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WEEKLY June 20–26, 2020

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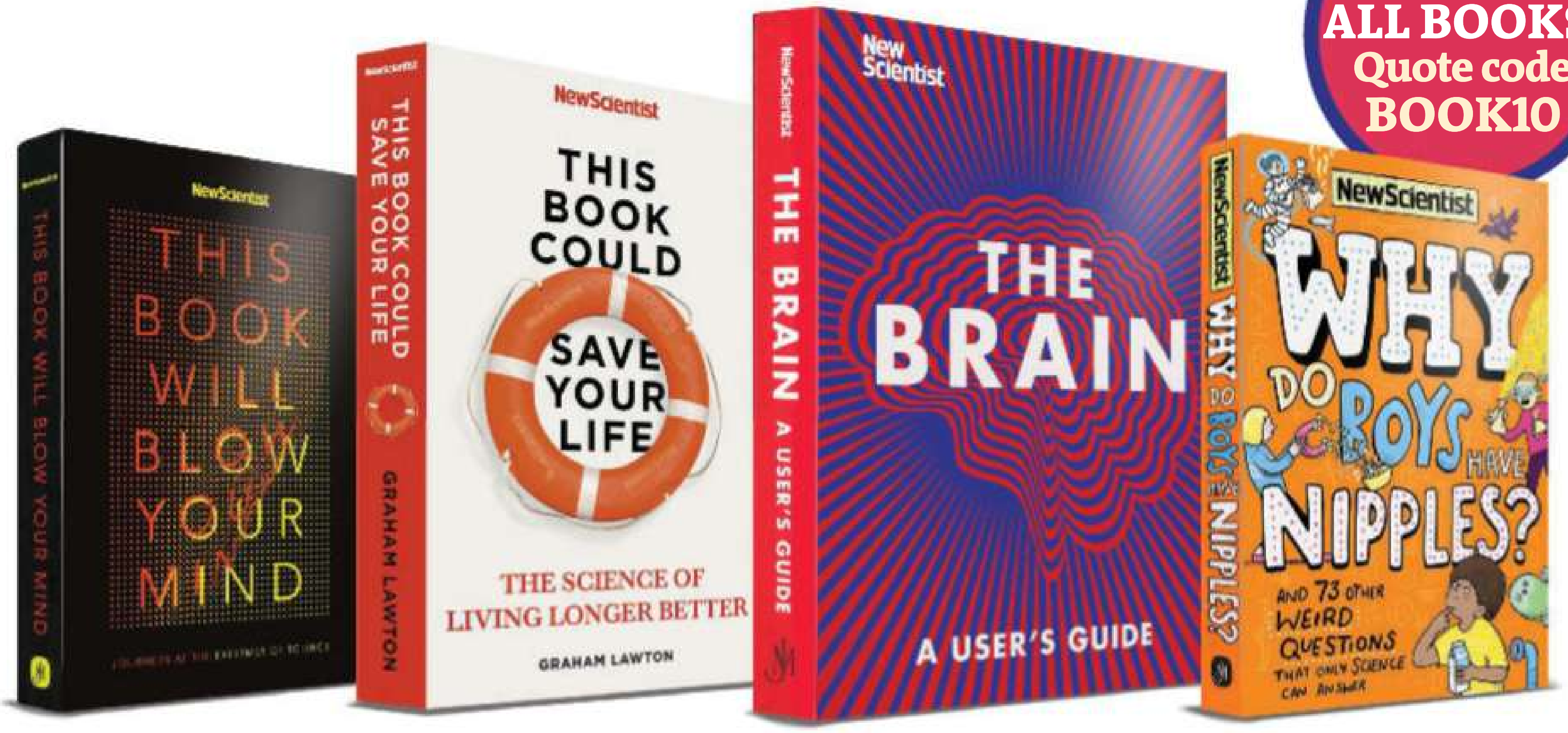
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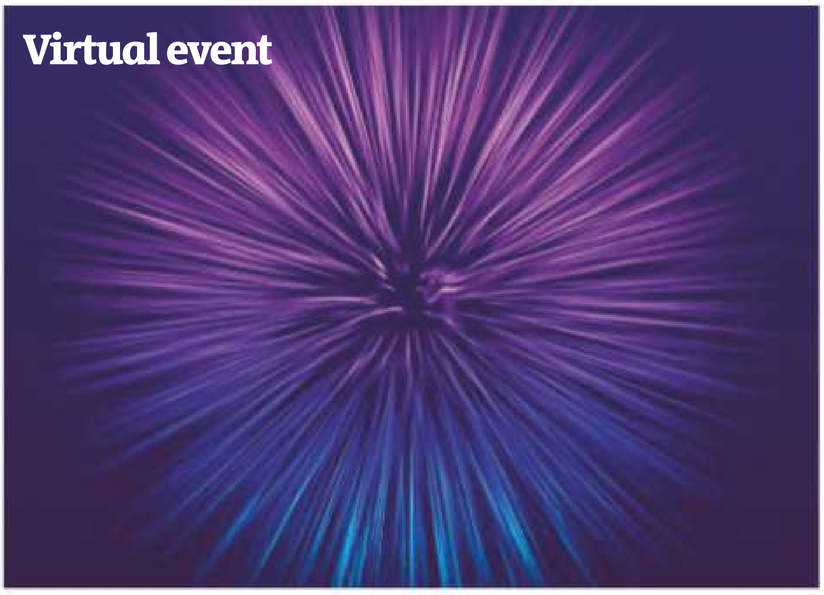

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Mysteries of the big bang Dan Hooper on the origins of everything

MARY ALTAFFER/AP/SHUTTERSTOCK

Mega-dino Settling the debate over Earth's largest land animal

JOHN GAFFEN/ALAMY

Human origins Geneticist David Reich untangles our complex history

Video

Where we come from

Harvard geneticist David Reich and his team are DNA testing the bones of ancient humans. Their explosive results are still coming in, but one thing is already certain: much of what we thought we knew about human history is wrong.

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Online

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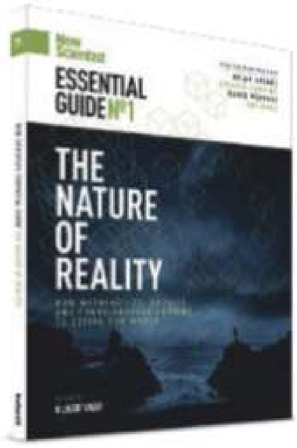
newscientist.com/coronavirus-latest



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The battle plan

There will be another pandemic. The good news is, we already know what to do

AS SOME countries take tentative steps back towards normality, thoughts inevitably turn to the future. What lessons are there from missteps made this time that we can apply to preparing for the next pandemic? Because, even though its nature, timing and deadliness cannot be known, we can be confident that there will be another. The forces that led to this one, including ever-greater international trade and travel and encroachment on wild areas, may be taking a short break, but will be back.

In an ideal world, once the virus was properly under control, leaders would come together to take stock and produce a series of thoughtful steps to prepare for the next pandemic. Yet even in places that are easing restrictions, this current outbreak is far from over. In many parts of the world, it is only just getting going (see page 8). That means the knock-on effects of the complacency, short-termism and nationalism that have defined much of the patchwork preparations and response so far are still playing out. None of this is conducive to future pandemic planning.

> “We cannot afford to wait for the current pandemic to be over before we prepare for the next one”

However, we cannot afford to wait for this one to be over before we prepare for the next. There is good news though: a plan already exists. You could be forgiven for not realising this, in light of some of the responses so far. Even though it isn’t perfect, it is a decent starting point for a more comprehensive plan (see page 30).

For a start, international regulations agreed by nearly 200 countries set out exactly how to identify a potential pandemic, the time frame for raising the alarm and even best practice for collaborating across borders and at international entry points. But agreeing to plans is one thing, sticking to them and seeing them through quite another.

Perhaps it is a matter of reframing. “The world needs to prepare for pandemics in the same serious way it prepares for war,” said Bill Gates in 2018. Most countries maintain extensive military defences – at great cost – in the hope of never having to use them.

That should apply here too. We have seen how a virus can kill people and destroy economies. Safeguarding against this threat can no longer be considered an unaffordable luxury. ▮

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Adam
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CHRISTOPHER BROWN/ZUMA WIRE/SHUTTERSTOCK

A drive-through coronavirus testing site in Tucson, Arizona

Second waves in the US

Twenty-one US states have seen a surge in covid-19 cases in recent weeks, many after lifting restrictions, reports **Maddie Bender**

ARIZONA, North Carolina and Florida are all US states that are now experiencing a spike in confirmed coronavirus cases while lifting stay-at-home orders.

On 10 June, the US surpassed 2 million confirmed cases of covid-19, representing an increase of more than 140,000 from the previous week. Around two months ago, the country saw a weekly increase in confirmed cases of more than 210,000, largely due to hotspots such as New York City and Seattle, Washington.

Rates of new cases in each of those cities, along with the percentage of tests that are positive, have now decreased. But places that weren't as severely affected by the first peak are driving the recent increase, including regions of Arkansas, Georgia and California.

In Florida, the stay-at-home order took effect on 3 April. That week, 6820 confirmed cases had been reported. The state has been reopening since 4 May, and 8886 new cases were reported between 4 and 11 June. The lifting of stay-at-home orders has now been delayed in parts of Oregon, Utah and Tennessee.

But some states haven't yet had a first peak in cases. In Arizona, the number of cases is still climbing, with more than 13 per cent of coronavirus tests being positive as of 12 June, according to data from The COVID Tracking Project, almost three times higher than the national average.

"We are seeing an increase of cases coinciding with the reopening process," says Rebecca Fischer at Texas A&M School of Public Health. She says that it is tricky to determine the cause, particularly as the US celebrated Memorial Day at the end of May, a holiday usually associated with social gatherings. "It's really tough to attribute the timing, per se, to an event."

Texas's stay-at-home order expired on 30 April. When that occurred, many people resumed the kinds of person-to-person contact that spread the virus, says Fischer. Interactions following reopenings could have increased community transmission and contributed to the spikes that 21 states are now experiencing.

But reopening is just one of several factors at play. A lack of social and health infrastructure, lags in testing, confusion in case-reporting and individual risk-taking behaviour have also advanced the spread of the virus.

Bradley Dreifuss at the University of Arizona in Tucson says that efforts to prevent and treat coronavirus infections in Arizona have been stymied by pre-existing barriers to medical care.

> "People value independence and haven't taken kindly to the restrictions that come with physical distancing"

For example, the Navajo Nation, part of which is located in Arizona, is considered a hotspot of the current surge. The health service used by the Navajo Nation allocates $3943 per person a year, while the average person in the US spent around $5000 on healthcare in 2019. Native American populations also tend to have more underlying – and costly – health conditions than the average person in the US.

An additional issue is willingness to observe coronavirus measures. Both Fischer and Dreifuss say that people in their regions value independence and haven't taken kindly to the restrictions that come with physical distancing. It is still possible to re-flatten the curve, though. "The horse has definitely left the barn, but I don't know if it's left the farm," says Dreifuss.

Stemming this rise in cases will require effort from both individuals and policy-makers. The US will have to implement regular, large-scale contact tracing and testing for entire workplaces and communities, as well as provide a support system to healthcare workers on the frontline, says Dreifuss. ▮

Daily coronavirus news round-up
Online every weekday at 6pm BST
newscientist.com/coronavirus-latest

Global spread

8 million cases worldwide

Death toll approaches half a million, but pandemic is still in its early stages

Adam Vaughan

ELLAN LUSTOSA/ZUMA WIRE/PA IMAGES

Pits dug on the beach in Rio de Janeiro to protest against Brazil's government

"I THINK when you're sitting in Europe, you feel like you just had the epidemic and everyone's coming out of it. It feels like it's over with. But it's actually just at the start in every country in some ways," says Azra Ghani at Imperial College London of covid-19's spread.

Her view is backed up by World Health Organization (WHO) statistics, which show that the world experienced its highest daily jump in new confirmed coronavirus cases on 7 June, a record that, when *New Scientist* went to press, had since been broken three more times.

"Although the situation in Europe is improving, globally it is worsening," said WHO general secretary Tedros Adhanom Ghebreyesus at a press conference on 8 June.

The virus's spread continues as the world rapidly approaches the grim threshold of half a million confirmed deaths, with more than 437,000 reported as of 16 June. Early this week, the milestone of 8 million confirmed cases worldwide was passed. Because not all cases are detected, the real total and death toll are likely to be much higher.

The geographical burden is shifting. While the US is still worst affected, with over 2 million cases of coronavirus and more than 100,000 deaths, it is now followed by Brazil, Russia and India, and then mostly European countries.

Peru has the eighth most cases, and the WHO has called South America the new epicentre of the epidemic. The Middle East's share of global new cases has climbed too in the past fortnight. Cases in Africa are still relatively low, but are speeding up: reaching 100,000 took 98 days, but 200,000 just 18 additional days.

Worldwide, the average number of daily new confirmed cases has settled at a higher level in June than in May.

However, David Heymann at the London School of Hygiene and Tropical Medicine says deaths, rather than cases, are the gold standard for measuring transmission, despite reflecting events around two to four weeks in the past. Unlike cases, global daily deaths are relatively static, averaging 4295 in June so far, versus 4619 in May.

Heymann, who led the WHO's response to the SARS coronavirus outbreak in 2003, says the upward trend in cases could be a result of more testing and a reflection of the different strategies nations are employing. "It's really apples and oranges in the same basket because some countries are doing additional testing for contact tracing and throwing positives into the basket, and other countries aren't doing that," he says.

"Although the coronavirus situation in Europe is improving, globally it is worsening"

The large number of new confirmed cases may be partly due to greater testing capacity and tracing efforts, says Ghani. But she suspects another reason they are ticking up is that many countries are beginning to emerge from lockdown.

In some nations, such as Germany, there has been a slow increase in detected infections, while in others, including Iran, the increase has been faster, raising fears of a second peak. Some lockdown restrictions are now being reintroduced in Beijing, China, where 106 new cases had been confirmed as *New Scientist* went to press.

A WHO spokesperson says: "The biggest threat we now face is complacency. All countries have unique epidemiological curves. Some that brought large outbreaks under control have seen flare-ups. Whether a flare-up becomes a second large outbreak is down to whether or not strong public health interventions are established."

Ghani is particularly worried about low and middle-income countries that cannot sustain lockdowns for economic reasons and have weaker healthcare systems. Modelling she has done with colleagues projects that deaths will accelerate across the next 28 days in Brazil, India, Pakistan, Russia and South Africa, along with many other countries.

Covid-19 now appears to be with us all for good, she says. "There's been fantastic successes in New Zealand and Australia, and South-East Asia, but given the global spread, I think we have to consider it endemic now."

Yet even though the coronavirus is widespread, the actions taken to control and limit the transmission of the virus can still have a big effect on how many people will ultimately catch it. An initial analysis by Ghani offers some hope that people are adapting to the coronavirus in ways that mean second peaks of covid-19 outbreaks aren't inevitable.

Before lockdowns, movement patterns tracked using data from Google and elsewhere were a good predictor of new cases. But as some richer countries emerge from restrictions, the correlation between cases and movement has weakened, she has found, in as-yet unpublished work.

"Face mask wearing has become more widespread. When we start to move around, we're probably staying a bit further apart from people, we're not having the close contact, the handshaking. And maybe we're avoiding contexts where transmission might occur," says Ghani. "That's a positive sign. If that's sustained in coming weeks, it suggests we are learning a way to live with the virus." ▮

Travel

How international travel for business and holidays can resume

Michael Le Page

MUCH of the world is starting to open up again, with many countries easing or planning to ease coronavirus travel restrictions. But would-be travellers face a confusing, uncertain and fast-changing situation.

As the coronavirus first spread around the world, a lot of countries – but not all – closed their borders to varying extents. Some require all travellers to self-isolate or to be quarantined in special facilities for 14 days after entry. Others allow only their own citizens to enter.

These measures have helped control the spread of the coronavirus. "Travel bans actually do work, as we see with China and New Zealand," says Julian Tang at the University of Leicester in the UK.

But the economic and social costs are enormous, especially for places that are heavily reliant on tourism. Many countries are now trying to ease travel restrictions without triggering a resurgence in infections. They are taking a variety of approaches, even inside the European Union.

Cyprus unilaterally opened up to a small number of specified European countries – not including the UK – from 9 June. This means travellers from these countries will no longer have to self-isolate after entry.

Similarly, France, Germany and a few others reopened to most European countries from 15 June, with France asking visitors from some countries to voluntarily self-isolate.

Greece is now allowing visitors to enter without self-isolating, provided their flight comes from an airport that isn't on a list of airports deemed to be high risk by the European Union Aviation Safety Agency – though the list is intended only as a guide to what disinfection procedures are needed. A few UK airports aren't on this list.

Spain will begin reopening from 1 July. It plans to trial a system under which tourists will be tested on arrival and will have to remain isolated in their hotels for 6 hours as they await the results.

14 days

The length of quarantine faced by travellers from the UK to Estonia

The problem with unilaterally reopening, however, is that would-be visitors may still face self-isolation or quarantine on their return home. The UK, for instance, introduced 14 days of self-isolation for travellers, including returning residents, on 8 June. For some, such as those able to work from home, self-isolation on return may not be a major issue, but it will deter many others.

One way to avoid this is to set up travel bubbles – groups of countries with similar levels of coronavirus infections that allow people to travel between them without having to self-isolate or quarantine, though travellers may have to undergo testing.

Researchers say the idea makes sense. "Our model would support the creation of bubbles from a pure spreading point of view," says Ellen Kuhl of Stanford University in California. "Easing travel restrictions between two countries that are equally affected should not produce an added risk."

On 14 May, Estonia, Lithuania and Latvia allowed free travel to resume between them, creating what may have been the world's first "travel bubble", and some other countries are considering similar arrangements.

"Easing restrictions has not resulted in an increase in infections," says a spokesperson for the Estonian Ministry of Foreign Affairs. On 1 June, the Baltic states effectively dissolved the bubble by reopening their borders to other European countries.

Travellers wearing face masks at Charles de Gaulle Airport in France

ADRIENNE SURPRENANT/BLOOMBERG VIA GETTY IMAGES

Now, only people arriving from a country with an infection rate that exceeds 15 infections per 100,000 inhabitants for the previous two weeks – including the UK, Sweden and Ireland – must remain in quarantine in Estonia for 14 days. This approach means travellers might unexpectedly find themselves quarantined if there is a second wave on infections in their home country while they are away.

Travel corridor

Australia and New Zealand, meanwhile, are discussing setting up a "Trans-Tasman bubble" that may also include nations such as Fiji. Australia is also in talks with Singapore, which is setting up a limited travel bubble with China based on testing travellers before and after arrival.

On 1 May, China set up a "travel corridor" with South Korea, allowing shortened quarantines for business travellers flying between specific destinations.

In theory, countries in the Asia-Pacific region that are successfully controlling the coronavirus could form a "mega-bubble", but there are many obstacles.

One is that several states within Australia have closed their borders to people from other parts of the country, with Queensland saying it may not reopen all its borders until September, for example. It is hard to see how the country could join international bubbles while some internal borders are closed.

Relaxing restrictions is risky. But infected travellers won't necessarily spark local outbreaks, says Moritz Kraemer at the University of Oxford. Such outbreaks can be prevented by rapid isolation of cases, effective contact tracing and extensive testing, he says. ■

Infection rate

How many have caught coronavirus?

Estimating the number of people who have caught the coronavirus is tough because of inconsistent case reporting and varied testing methods, finds **Jessica Hamzelou**

JUST how many people have been infected with the coronavirus? Statistics are trickling in from cities and countries around the world, but the figures vary hugely. Some regions are reporting that less than 1 per cent of people have been infected, and others that over half the population has had the virus.

How are these figures calculated, and which can we trust? Determining the true prevalence of coronavirus infection will be important for understanding how the virus spreads and limiting its damage.

The reporting of coronavirus cases varies drastically around the world. Tim Russell and his colleagues at the London School of Hygiene and Tropical Medicine have estimated that, as of 15 June, more than 95 per cent of symptomatic cases have been reported in some countries, including Ghana, Kazakhstan, Morocco and Oman.

However, the team estimates that only 35 per cent of symptomatic cases have been reported in the US, and the figure is even lower for some other countries. The UK is estimated to have reported only 14 per cent, Sweden about 19 per cent and Yemen just 3 per cent.

What these statistics don't reflect is the number of symptomless cases, which some evidence suggests can account for between a quarter and half of all coronavirus infections.

Two ways to estimate

When it comes to estimating prevalence, there have been two main approaches. Researchers have either tested a sample of people in a population and directly reported those numbers, or predicted how the virus has affected a population using mathematical models.

As a starting point, many modellers have turned to the case of the Diamond Princess, a cruise ship that experienced one of the first large outbreaks of the coronavirus. Most of the 3711 people on board were tested for the virus – 712 were found to have been infected, and at least 13 people have died.

Russell and his colleagues have used this and other data sources, such as European Centre for Disease Prevention and Control data, to predict how many people have been infected with coronavirus in various countries. Because the quality and quantity of the testing and reporting is inconsistent across the world, the team says it is difficult to get an accurate picture of the true number of infections.

It may be possible to come up with an estimated global rate of infection, but due to missing data, it may not be a very good one. One way to get around this is to look at the overall number of deaths from all causes. "If you're seeing way more deaths, you're probably not detecting anywhere near as many cases as you have," says Russell.

> "The quality and quantity of testing is inconsistent, so it is difficult to get a true number of those infected"

A contact tracing advert on a billboard in London this month

NHS
NHS TEST AND TRACE
SELF-ISOLATE WHEN ALERTED
STAY ALERT · CONTROL THE VIRUS · SAVE LIVES

REUTERS/HANNAH MCKAY

Henrik Salje at the University of Cambridge and his colleagues have done similar modelling for France. Their technique involves incorporating data from sources like the Diamond Princess and hospital records, and filling in gaps by estimating how many people might have had infections that aren't severe enough to require hospitalisation, which is more common for women and younger individuals.

By their estimate, as of 11 May, around 4.4 per cent of the population of France had been infected with the coronavirus. The figure varies by region, and the hardest hit area of the Ile-de-France region, which includes Paris, is thought to have had a prevalence of 9.9 per cent by then.

These figures are broadly in line with others resulting from direct antibody tests, which can reveal whether a person's immune response has encountered the coronavirus in the past.

So far, antibody tests in Spain, Italy and England put the proportion of people infected at between 2 and 5 per cent, although, again, the prevalence

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is higher for densely populated cities like London and Madrid.

These tests work by searching for specific antibodies – proteins made by the immune system that help defend against infection. In the case of the new coronavirus, most antibody tests search for immunoglobulin G, which is the most common type of antibody and typically sticks around in the blood longer than others, says Juliet Bryant, a consultant for the World Health Organization.

However, we don't yet know the role such antibodies might play in conferring any immunity to the coronavirus.

A global effort

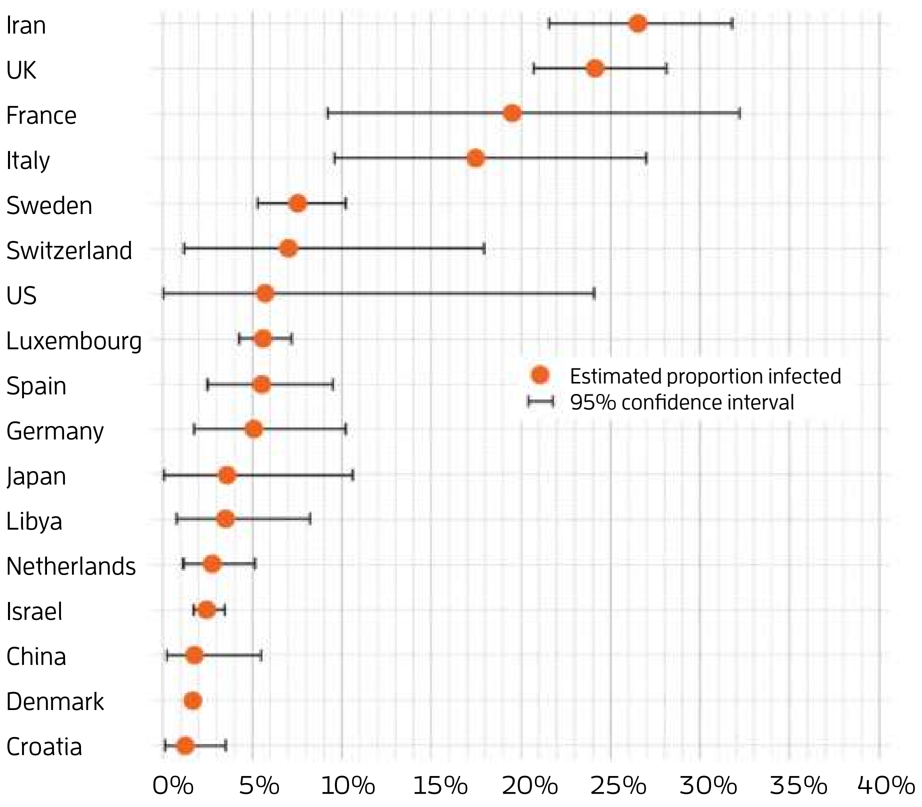
In May, Niklas Bobrovitz at the University of Toronto in Canada and his colleagues formed a team of scientists in six countries to collate and assess blood test data to determine the proportion of people globally who have been infected with the coronavirus.

Many regional figures come from studies that haven't been through the peer-review process yet, and some come from public health bodies or private health agencies. Sometimes, the information comes in the form of a tweet from an elected official.

So far, there are more than 100 of these prevalence figures, says Bobrovitz, although that number is growing on a daily basis. "There's a huge variation, between 0.4 and 59 per cent," he says.

The team can't be sure what is driving these differences. There could be real differences in the prevalence rate, perhaps due to the age or health of the population, or policies to control transmission of the virus. "Very likely, it's down to differences in the study methodology used," says Bobrovitz.

The proportion of people estimated to have caught the coronavirus in different countries varies widely



SOURCE: SEROTRACKER.COM, LAST UPDATED 15 JUNE

There are a variety of coronavirus tests, and each will have its own sensitivity and specificity. These two measures give an idea of how many test results will be false negatives or false positives, respectively. In some cases, studies don't report the accuracy of their tests.

While some researchers have looked at antibody levels in the general population, many have focused on groups that are easier to study, such as healthcare workers and blood donors. A large majority of the studies that Bobrovitz and his colleagues have assessed so far are considered to have a moderate or high risk of bias in their reporting. A study that includes blood donors, for example, is likely to over-represent young people.

26%

of people have been infected with coronavirus in Stockholm

One of the more robust studies has been conducted in Spain, where authorities recruited more than 60,000 members of the general population. So far, the results of testing suggest that about 5 per cent of the population across Spain has been infected, although the figure is 10 per cent in Madrid.

Far from herd immunity

Despite the problems with these studies, it is clear that even countries with high prevalence are nowhere near the level needed to allow herd immunity, which can stop infections spreading through populations. For the majority of known viruses, at least 70 per cent of the population must have immunity to achieve this communal protection.

This level of infection hasn't been observed in any study, not even in Sweden. The country has become a poster child for the anti-lockdown movement, due to the comparative lack of restrictions on daily life to control transmission of the virus. Sweden has reported more deaths per capita than neighbouring countries, but modelling by the country's health authority estimates that only around 26 per cent of the population of Stockholm County had been infected with the virus by the start of May.

Salje thinks this is probably an overestimate. The virus is likely to cause a similar percentage of deaths across countries, he says. If more than a quarter of the Swedish population had been infected, "you would expect to have seen many more deaths", he says.

Getting our heads around how many people have been infected by the coronavirus isn't simply a matter of tracking the progress of the pandemic. Understanding how many people have had a virus can help shape public health policies by showing what works and what doesn't when it comes to limiting the spread, says Bryant.

Working out overall numbers and whether people have had the virus would therefore be of great benefit. But even if an antibody test were perfect, and delivered no false positive or negative results, we still wouldn't know if previously infected people will have immunity against the coronavirus or how long such immunity might last.

And when tests return false positive and negative results, they can give people the wrong idea about whether they are likely to catch or spread the virus. However, when we know the rate of false results, we can still get a good idea at the population level of how many people have had the virus. "Even a crappy test can be useful if you use it at the population level," says Bryant. ▮

Cosmology

Web of matter is spinning across the universe

Leah Crane

THE cosmic web is spinning. Our universe is full of enormous filaments of matter that stretch between galaxies in a vast, interconnected web – and simulations suggest that those filaments are rotating.

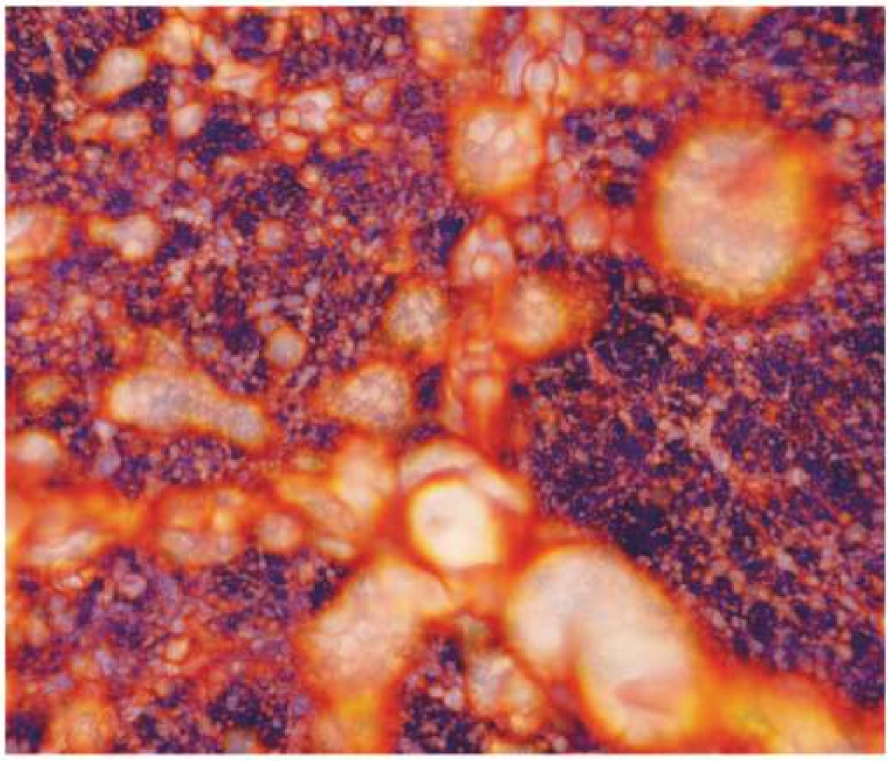
We know that all galaxies spin and that their rotation can be affected by their environments, including any nearby filaments of matter, but we didn't know whether these huge, thread-like structures also rotate. Now, Qianli Xia at the University of Edinburgh, UK, and his colleagues have used simulations of how dark matter behaves in filaments to figure out how they might be moving.

The researchers combined simulations of nearly 34,000 filaments to measure their spin, and found that their average rotational velocity was about 80 kilometres per second. They estimated that about 26 per cent of filaments in the universe have noticeable spin (arxiv.org/abs/2006.02418).

"I'd really like to be able to measure this in the real universe," says Nick Kaiser at the École Normale Supérieure in Paris. "That's super hard, because the observations are very noisy, and in an individual object, you're not going to see much of that effect – you have to stack them."

Although the spinning would be difficult to spot in the real cosmos, the prediction that it exists isn't particularly surprising, as we expect most large objects in space to rotate based on how they form, says Alan Heavens at Imperial College London.

In the simulation, the researchers found that this spinning occurs because of what astronomers call tidal torque. As a clump of matter – a cloud of gas, for example – falls towards a filament, the closer part of it experiences stronger gravitational forces than the most distant part, causing it to spin. When it falls into the filament, that spin gets passed on as well.


SCIENCE HISTORY IMAGES/ALAMY

Simulations have revealed that the universe's web of matter may be rotating

"If these filaments are spinning themselves, you would expect that that has a consequence for the galaxies that are living in them," says Rien van de Weijgaert at the University of Groningen in the Netherlands. "If you are interested in the origin and evolution of galaxies and, in the end, where our Milky Way came from, this is the kind of stuff that's important." The fact that filaments spin could help refine our understanding of why galaxies spin.

It could also help explain another deeper mystery: where the magnetic fields that suffuse the cosmos come from. "We know the mechanisms which would amplify pre-existing magnetic fields, so we know of ways of taking a very small field and making it bigger, but that begs the question of where did the very small field come from?" says Heavens.

Magnetic fields come from the movement of charged particles, but we don't know which particles are responsible for galactic-scale fields. If the particles that make up the filaments have any electric charge, they could create the small magnetic fields that are magnified by galaxies and clusters of galaxies.

At its most basic, this finding allows us to understand the backbone of matter in our universe. "The largest structure in the universe is the cosmic web," says van de Weijgaert. "Now we are starting to see its properties, and it is moving from something abstract into something that is real and has real physical characteristics." ▮

Biotechnology

Goat milk could make cheaper cancer drugs

Alice Klein

GOATS can be genetically modified to produce a common cancer drug in their milk, which could slash its production costs.

A team led by Goetz Laible at AgResearch, a government-owned research institute in New Zealand, wanted to find out if it could make the bowel cancer drug cetuximab cheaply and at high volumes by genetically engineering goats to produce the protein in their milk.

The drug, which is sold under the name Erbitux, is a complex protein called a monoclonal antibody that is expensive to make. It costs around £3000 a month for a single patient in the UK.

First, the researchers inserted genes into goat embryos that carried instructions on how to make cetuximab in the mammary glands.

Female goats were then impregnated with the embryos and their genetically modified offspring were born five months later. The offspring were all female and once they began lactating, they were able to produce about 10 grams of cetuximab in each litre of their milk.

Since goats produce about 800 litres of milk every year, this means that each could manufacture multiple kilograms of cetuximab in a year (bioRxiv, doi.org/dzhp).

"The goats were able to produce about 10 grams of a cancer drug in each litre of their milk"

The genetic modification didn't appear to affect the goats' health, says Laible.

Goats producing this amount of cetuximab in a year would be "excellent productivity", says Stephen Mahler at the University of Queensland, Australia.

But we need to be sure that drugs derived from animal milk have the same standard and purity as normal, he says. ▮

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Black Lives Matter

Researchers on strike

Academics, journals and scientific institutions joined anti-racism protests

Leah Crane and Layal Liverpool

SCIENTISTS around the world went on strike on 10 June to raise awareness of institutional and systemic racism against Black academics. This event comes in conjunction with widespread protests against police violence after the killing of George Floyd, who died on 25 May after a Minneapolis police officer pinned him to the ground by his neck.

The strike was organised by a group of academics, many of them physicists and astronomers based in the US, and promoted on social media with the hashtags #ShutDownAcademia, #ShutDownSTEM and #Strike4BlackLives.

The organisers encouraged academics across STEM (science, technology, engineering and mathematics) fields to take the day away from their normal research and instead spend it educating themselves on racial disparities in their field and taking action against racial violence and discrimination. At least 5800 academics based at universities from around the world took part.

"As academics, we do not exist in a vacuum and it is important to recognise the current events: Black members of our communities are being harassed and lynched with little to no consequence, as well as being disproportionately affected by the current pandemic," says Tien-Tien Yu, a particle physicist at the University of Oregon who has helped organise the event through the Particles for Justice group. "We need to acknowledge that this takes a toll on the well-being of Black academics and that Black Lives Matter."

The organisers say they want the event to inspire academics to hold their institutions to a higher standard. "We hope everyone comes out of this with concrete steps they can take and ask for from their academic institutions," says Seyda Ipek at the University of California, Irvine, another particle physicist and member of Particles for Justice. Those steps could include hiring more Black faculty members, interrogating how researchers' academic work is used in broader society and making university campuses safer and more welcoming for non-white students.

ERIK MCGREGOR/LIGHTROCKET VIA GETTY IMAGES

It is also an opportunity for Black researchers to take a break from their everyday work, which many are trying to do in the midst of a global reckoning about racism. In the interests of that, a number of scientific institutions participated in the strike by either shutting down for the day or releasing resources for people hoping to make a difference in the racial dynamics of academia.

The journal *Nature* delayed its online publication on 10 June to allow staff to "spend the day planning how to help eradicate anti-Black racism in academia and

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Analysis **Beyond protest**

What action will follow the strike?

Many Black scientists and academics have suggestions, finds **Layal Liverpool**

WHILE statements of support for the 10 June strike (see "Researchers on strike", above) have been welcomed, many are keen for institutions to go further. "People are tired of seeing organisations that have released statements, but with no action plan in place," says Jasmine Roberts at The Ohio State University.

Black scientists who spoke to *New Scientist* had a number of suggestions for further action by scientific journals that supported the strike, such as inviting more Black academics to write review articles, peer review scientific papers and serve on editorial boards.

"There are currently no Black editors on the *Nature* journal," says *Nature*'s editor-in-chief Magdalena Skipper. "The implications of the lack of Black representation in our editorial staff are not lost on us." *Cell*, another scientific journal, published a statement acknowledging that none of its editors are Black.

Journals can't solve this problem alone, however. Several universities have released statements condemning racism, but many were criticised for their failure to explicitly mention Black people or to lay out plans for addressing inequalities.

<1%

of university professors in the UK are Black

There is mounting pressure for universities to acknowledge their racist histories and incorporate this into their curricula. An inquiry into the history of eugenics at University College London (UCL), for example, was criticised earlier this year for failing to investigate the issue in sufficient depth.

On 11 June, UCL announced it would immediately start reviewing the names of spaces and buildings that were named after two prominent eugenicists, Francis Galton and Karl Pearson.

But UCL is just one of many

A portrait of George Floyd held during an anti-racism march in New York

STEM", according to an editorial published by the journal. In a separate editorial, *Nature* condemned racism and police violence, while acknowledging the journal as "one of the white institutions that is responsible for bias in research and scholarship".

ArXiv – a website where researchers across STEM fields post drafts of papers before formal publication – also participated in the strike, discouraging researchers from submitting papers on 10 June. Most days, the site sends an evening email announcing the latest papers, but it cancelled the announcement for the evening of 9 June.

"I want a day where I don't have to worry that I've missed an important paper on the arXiv because I am stressed out while my non-Black colleagues happily keep going," said physicist, organiser and *New Scientist* columnist Chanda Prescod-Weinstein at the University of New Hampshire in a statement released by arXiv. "The strike is not just about gathering people together to begin to take action, but it is also about a day of rest for the people most affected by this heated moment."

PNAS, another scientific journal, also delayed its regular email announcement in support of the strike, and instead sent an email saying it stands "in solidarity with Black academics and STEM professionals".

Several university departments also participated in the strike by shutting down on 10 June, and CERN, home of the Large Hadron Collider near Geneva, Switzerland, postponed an academic session in a virtual four-day scientific meeting, moving it from 10 to 11 June in solidarity with the strike. The Massachusetts Institute of Technology Twitter account also went dormant on 10 June.

"We hope everyone comes out of this with concrete steps they can take and ask for from their institutions"

A number of other academic institutions published statements in support of the strike, including the American Association for the Advancement of Science (AAAS), which owns the journal *Science*, as well as the American Astronomical Society, the American Mathematical Society and the UK-based Institute of Physics. AAAS encouraged its members to post suggestions on social media of ways to eliminate racism and make STEM more inclusive of Black people.

The strike organisers built a web page with a number of resources and suggestions for actions that academics could take during and following on from the strike, which they hope to be a jumping-off point for bringing the issues that Black researchers face to the forefront and beginning a long-lasting campaign of change.

Prior to the strike, many Black academics had already taken to social media to share their personal experiences of racism in academia, for instance under the hashtag #BlackInTheIvory, and to call for higher education providers to confront systemic racism within their institutions.

"In the short-term, we hope that non-Black academics take immediate action to fight against anti-Black racism," says Ipek. "But this movement has to be sustained on a much longer timescale. Hundreds of years of anti-Black racism will not be erased from our Ivory Tower in one night." ▮

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institutions worldwide that have buildings, lecture theatres or statues dedicated to scientists or other historical figures who held racist views or participated in racist acts. "Universities should stop celebrating individuals that are known to be racist," says Cassandre Coles at the University of Illinois at Chicago.

To tackle racial bias and discrimination, academic institutions should penalise academics who make racist comments or exhibit racist behaviour, says Amber Lenon at Syracuse University in New York.

Universities should also be more deliberate about increasing their representation of Black people. Fewer than 1 per cent of university professors in the UK are Black, according to recent figures from the UK's Higher Education Statistics Agency. In the US, less than 5 per cent of full professors are Black.

UCL

University College London's Pearson building

Allocating more funding towards equality, diversity and inclusion work is an important starting point, says Madina Wane at Imperial College London. "Currently, much of this work is performed, with little recognition, by underrepresented groups in addition to their actual contracted work," she says.

Overall, many Black scientists see the 10 June strike as the start of a process. "No one group has a monopoly on intelligence, creativity and ideas," says Nira Chamberlain, president of the UK's Institute of Mathematics and its Applications. "As a scientific community, we must work much harder to create a more diverse workforce from the top to the bottom." ▮

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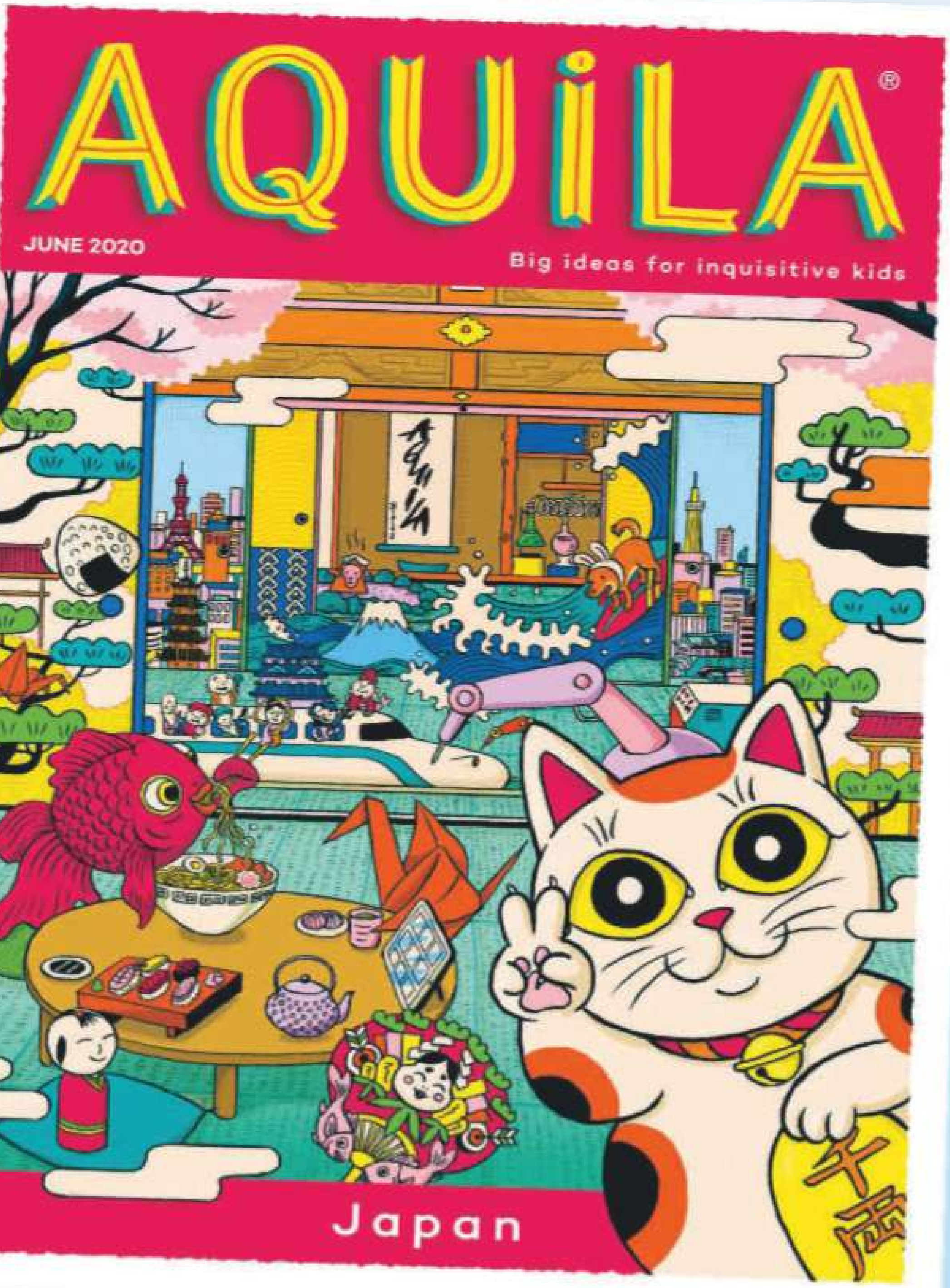

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Health

Spleens could be transformed into livers to treat organ damage

Alice Klein

THE spleens of mice can be altered to help them survive liver damage. If the same approach works in people, it could offer an alternative to liver transplants.

People who need new livers often have to wait a long time for a donor organ to become available. Scientists have tried engineering livers in the lab, but have found it too difficult to recreate their intricate networks of blood vessels.

Lei Dong at Nanjing University in China and his colleagues wondered if, instead, they could transform an organ such as the spleen into a working liver, as survival is possible without a spleen and it has ready-made blood vessels.

To find out, they injected the spleens of live mice with a substance to make the organ larger, stiffer and better able to support the growth of new tissue. Next, they transplanted liver cells into the modified spleens to see if the cells would integrate with the existing blood vessels and develop into liver tissue.

Over the next eight weeks, the liver cells grew in the spleens and developed into liver-like organs, complete with bile ducts and other structures of the liver. The converted spleens could also perform essential liver functions such as drug metabolism (*Science Advances*, doi.org/dzbp).

Dong's team then removed 90 per cent of each real liver to see if the new spleen-based livers could take over. All the mice with spleen-based livers survived, whereas other mice died within two days of having liver tissue removed. "Our results suggest that we have transformed the spleen into an organ that functions as a liver," the researchers write.

In humans, the spleen isn't essential and can be removed for medical reasons. Dong and his colleagues suggest that repurposing people's spleens to act like livers could help them overcome liver disease without causing other complications.

However, spleen-based livers couldn't perform all of a real liver's functions because they are hooked up differently to the circulation, says Geoff McCaughan at the University of Sydney, Australia. For example, the liver detoxifies blood coming from the portal vein, which the spleen has no direct access to, he says.

Another issue is that people with serious liver disease often also have damaged spleens, which may make it difficult to transform them into liver-like organs, says Eric Lagasse at the University of Pittsburgh, Pennsylvania. "It will take a while to see if such an approach works in humans or is even feasible," he says.

If it isn't, one solution may be to develop liver-like organs in the lymph nodes instead, which are well-suited to growing new tissue and are less prone to damage than the spleen, says Lagasse.

He and his colleagues have done this in mice with severe liver disease and hope to try the approach in people "very soon". Turning one organ into another "may be not such a crazy idea", says Lagasse. ▮

People who need liver transplant surgery face long waits to find a donor

MORSA IMAGES/GETTY IMAGES

Technology

Indian military pilots test eye-tracking tech in planes

PILOTS in India are trialling aircraft display systems that respond to eye movements and could let military pilots keep their hands on a plane's controls more often while flying.

Modern aircraft have electronic displays that show the plane's fuel level, geographical position or imaging system. Pilots can click the screen to the relevant page of information as needed, but doing so requires them to take one hand off the plane's throttle or control stick.

"When you are flying at different phases, you do not need all this information at the same time," says Pradipta Biswas at the Indian Institute of Science in Bangalore.

He and his colleagues devised an eye-tracking system embedded into a cockpit computer that allows a pilot to choose a relevant display simply by looking at the desired option and then confirming the selection by pressing a button on the control stick.

In a flight simulator, nine pilots tested this system on nearly 600 look-and-select tasks. It halved the time they took to complete the action (arxiv.org/abs/2005.13600).

The team has devised a second eye-tracking system that is worn on a pilot's head and responds to head and eye movements. The researchers tested it in a simulator by asking pilots to look at a button at the centre of the simulated windscreen, which they could select by focusing on it.

> **"Eye-tracking systems embedded into a cockpit computer let pilots keep their hands on the throttle"**

In a military setting, the head-mounted system could be used to automatically display information about a target in the distance if a pilot focuses their eyes on it, says Biswas.

To assess whether such devices could be used in real planes, the team asked three Indian Air Force pilots to use commercially available eye-tracking glasses as each flew a transport aircraft and performed standard selection tasks. Their average response time for each task was 2 seconds, just under half the time it usually takes. ▮

Donna Lu

Palaeontology

Fossil tracks may be from a bipedal croc

ANCIENT footprints first thought to belong to a pterosaur could actually have been made by a large bipedal ancestor of crocodiles about 110 to 120 million years ago.

Martin Lockley at the University of Colorado Denver and his colleagues found the fossil prints near Sacheon City in South Korea. They say the size and skin patterns of the tracks are consistent with those made by a crocodylomorph, a large ancestor of modern crocodiles that walked on two legs (*Scientific Reports*, doi.org/dzc6).

The findings suggest that other known footprints may also have been made by a crocodylomorph, rather than a giant flying reptile called a pterosaur, says Lockley. This was a surprise, he says. "No one knew that large bipedal crocs existed in the early Cretaceous." **Layal Liverpool**

Archaeology

Chinese art reveals ancient expertise

A TINY carving of a bird unearthed in China is one of the oldest known sculptures found there.

The artwork, made from the bone of an unidentified animal, probably depicts a songbird. Francesco d'Errico at the University of Bordeaux in France and his colleagues believe the carving is 13,000 to 13,800 years old, making it 8500 years older than others from China (*PLoS One*, doi.org/dzc8).

Whoever the sculptor was, they were highly skilled. Despite the figurine's small size, there are 68 identifiable worked areas, with traces of 10 different techniques used to work the bone, including flaking, gouging and polishing.

The bird's intricacy suggests there are older, simpler sculptures that haven't yet been found, says d'Errico. "This cannot come out of nothing." **Michael Marshall**

RUDMER ZWERVER/ALAMY

Metabolism

Brain switch offers clues to suspended animation

TWO groups of researchers have separately found a "brain switch" that makes starving mice enter a hibernation-like state to save energy. They hope it may be possible to induce similar states in people.

"Suspended animation could transform medicine and open the door to fantastic possibilities such as space travel and life extension," says Sinisa Hrvatin at Harvard Medical School.

Many birds and mammals, from hummingbirds to lemurs, lower their body temperature and enter a state of suspended animation as a way to survive tough times. Some hibernate through winters, others enter a state called torpor for hours or days to save energy.

Mice normally enter torpor only when they run out of food, but Hrvatin's team genetically engineered some so the activity of certain neurons could be controlled by injecting a chemical. Stimulating specific clusters of neurons in the brain's hypothalamus induced a torpor-like state in the mice, even in those that were well fed. Inhibiting these cells prevented mice entering torpor (*Nature*, doi.org/dzc3).

In a separate study, Takeshi Sakurai at the University of Tsukuba in Japan and his team identified the same brain switch in a different way. They looked for neurons in mice that made a protein that previous studies suggested was linked to torpor. They found that stimulating those neurons induced that state (*Nature*, doi.org/dzc2).

Being able to induce a similar state in people could have many uses in medicine, helping to treat everything from cancer to strokes and injuries, but it isn't clear whether this brain switch also exists in humans. **Michael Le Page**

Really brief

UPI/ALAMY

Even cosmic objects fall at the same rate

A key tenet of Einstein's theory of general relativity, that all objects fall with the same acceleration regardless of composition, has been upheld again. It was tested with the motion of a white dwarf and a pulsar orbiting another star (*Astronomy & Astrophysics*, doi.org/dzcf).

Eggs attract some but not all sperm

Chemicals from human eggs attract sperm more from some people than others. Researchers studied sperm and follicular fluid, which surrounds an egg, from 16 heterosexual couples. They found an 18 per cent difference in sperm count between the fluid that attracted the most and the least sperm (*Proceedings of the Royal Society B*, doi.org/dzbd).

Poverty relief also cut deforestation

An anti-poverty scheme has been linked with 30 per cent less forest loss in villages in Indonesia, which has the world's highest rate of deforestation. This was seen in satellite data taken near villages where people had received funds (*Science Advances*, DOI: 10.1126/sciadv.aaz1298).

New Scientist
Newsletter

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Leah Crane

Signal Boost

Welcome to our Signal Boost project. In these difficult times, we are offering charitable organisations the chance to take out a page in *New Scientist*, free of charge, so that they can get their message out to a global audience. Today, a message from **Games Aid**

GamesAid is a UK-based video games charity that acts as an umbrella for smaller charities who help vulnerable children and young people. We raise money from professionals operating in the video games business through networking events, comedy shows, golf competitions, poker nights, plus gaming livestreams, bundles and the sale of rare video game memorabilia. Since its inception in 2007, GamesAid has raised £3,770,000 for charities across the UK.

The charity has just a single full-time employee, and is operated by trustees who are volunteers from the games business. All of our events are created and run independently by people who work in the industry, while we also raise funds from company bake sales, raffles, individual sports challenges and more.

The charities that GamesAid supports are diverse and not exclusively related to video games. This year, we have raised money to support institutions dedicated to autism, neuroblastoma kids' cancer, children who face long-time care in hospitals, plus young people at risk of becoming homeless or living in unsafe environments. The charities are nominated and voted for by the games industry, and the successful recipients are revealed at a special event held every September.

GamesAid's mission is to help change the lives of disadvantaged children and young people, as well as supporting their families, through the generosity of those working in the video games business. We are always eager to welcome new collaborators and partners. You can contact us through Twitter and Facebook or on the web at gamesaid.org

Do you need your signal boosted?

If you are a charitable organisation working in science, medicine, technology, education or conservation, and would like to find out more about this project contact Chris Martin on chris.martin@newscientist.com

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The Bird Way reveals the hidden lives of birds through technology **p24**

Culture
Why it's more fun to be a mischievous goose than a bloodthirsty shark **p25**

Aperture
Flamingos fly above an otherworldly lake filled with minerals **p26**

Columnist

A very strange particle

We still don't know what the mass of a neutrino is, which means there is lots of exciting work yet to do, says **Chanda Prescod-Weinstein**

Chanda Prescod-Weinstein is an assistant professor of physics and astronomy, and a core faculty member in women's studies at the University of New Hampshire. Her research in theoretical physics focuses on cosmology, neutron stars and particles beyond the standard model

DURING my final year of high school, in 1998, my mother excitedly announced to me one day that neutrinos had mass. I didn't care, and I couldn't figure out why she did. At the time, I didn't realise what a big deal it was. I didn't even know what a neutrino was and arrogantly thought that because I hadn't heard about them, they weren't terribly important. By the time Takaaki Kajita and Arthur B. McDonald shared a 2015 Nobel prize for their role in the discovery, I knew more about these weird particles.

Neutrinos are, in my view, the strangest and most compelling members of the menagerie that we call the Standard Model of particle physics. They constantly pass through us and are hard to see. They fall into the family of particles called leptons. You are probably familiar with one lepton: the electron. The other two charged leptons are called the muon and tau.

Neutrinos are a different branch of the lepton family and like another particle you have probably heard of – the neutron – neutrinos don't have a charge. They are special in a way that neutrons aren't, however, as they are fundamental particles that can't be broken into smaller constituent parts, while neutrons are actually made of quarks.

Despite their differences in charge, the lepton family is bound together in interesting ways. Each charged lepton has a neutrino partner, so there are three kinds of neutrino: electron neutrinos, muon neutrinos and tau neutrinos. These partnerships aren't just a matter of naming convention, but they have meaning. In fact, the six flavours of lepton – because why say "particle" when you can say "flavour" – are organised into three generations.

Electrons are first generation, muons are second and taus are third, and the particles from higher generations tend to decay into the particles from the lower generations.

> **"Neutrinos are the strangest members of the menagerie that we call the Standard Model of particle physics"**

Curiously, these three particles get their mass through interactions with the famed Higgs boson, but mathematically, interactions with the Higgs leave the neutrino massless on paper. That is why neutrino mass is such an interesting topic.

Kajita and McDonald received their Nobel prize because they played a leading role in the first confirmed observation of something called neutrino oscillations, which occur if the neutrino has mass. What's fun about neutrino oscillations is that it is a phenomenon where effectively a neutrino is created with one flavour, but when it is measured, it has another flavour. In other words, if you make a muon neutrino, when you measure it, it might be a tau neutrino.

In fact, in 1998, scientists at the Super-Kamiokande (Super-K for short) experiment in Japan, observed this exact muon neutrino to tau neutrino transition. High-energy particles called cosmic rays hit the atmosphere regularly, and when they do, they produce muon neutrinos. These hit Earth at all angles, and because neutrinos pass through everyday matter pretty easily, they fly through the planet. The Super-K experiment observed that the neutrinos coming from the sky were muon neutrinos, but the ones coming up through Earth were tau neutrinos. Neutrino oscillations had occurred.

We didn't know whether neutrinos had mass for 50 years after they were discovered in the 1950s. Today, we still don't have a precise measurement, but we have confirmed the maximum value that their mass could be. This means we have been able to write off the hypothesis that dark matter is made of neutrinos. Their maximum mass is just too small.

What we are in need of is a theory to explain why neutrinos have a small, non-zero mass, and when you are a theorist like me, this is good news. ▮

Chanda's week

What I'm reading

I picked up T.J. Tallie's Queering Colonial Natal, *which is a good read that is teaching me a lot.*

What I'm watching

I'm pretty into Married at First Sight: Australia *right now.*

What I'm working on

I've been organising the global academic Strike for Black Lives and helping to lead national planning for the future of dark matter physics in the US.

This column appears monthly. Up next week: Graham Lawton

Editor's pick

Many ways to stay safer amid the pandemic

6 June, p 8

From Oliver Higson, Berlin, Germany

I write regarding Adam Vaughan's excellent article on why the UK has one of the highest death rates per million from covid-19 in Europe. I live in Berlin, where face masks have been mandatory for more than a month on public transport, in shops and in any place where people might gather. Even a bandana will do, but it must be in place before entry.

It is clear that the UK is and was behind the curve in so many ways concerning its pandemic response. A benefit of this belatedness might be to learn from others.

However, not to have already introduced the mandatory wearing of face masks in all situations where social distancing is almost impossible is tantamount to wilful neglect… or did I miss something?

From Hakan Lidbo, Stockholm, Sweden

I have made a "corona hat" so that I can keep my distance from my fellow citizens. It is very simple and cheap; the hat uses a reversing sensor from a car mounted in half a globe and is powered by batteries from a broken robot vacuum cleaner.

The sensor cost €20 and the globe was a broken one that I found in the trash. As the sensor's range starts at 1.5 metres, it is perfect for warning when people get too close. As Sweden was never locked down, social distancing is very important.

Green hopes may yet hit a red light

30 May, p 30

From Holly Goodrick, London, UK

In your interview with World Meteorological Organization head Petteri Taalas, you consider the positive impact of the covid-19 pandemic on reducing carbon emissions.

This crisis has given governments a great opportunity to reduce emissions, but whether they will capitalise on it remains in doubt.

We must also consider how the pandemic may hinder progress. I am concerned that the large costs incurred due to measures to stop the virus will mean that governments are less willing to invest in green energy technology. The need to put money into rebuilding businesses is likely to lead to governments prioritising cheap energy over clean energy.

An alternative way to look at our fifth appetite

23 May, p 30

From Norman Fry, Woolaston, Gloucestershire, UK

I was pleased to see the variability of human appetite explained as a combination of five separable components related to key nutrients. Could I suggest an amendment?

About a decade ago, I was monitoring my own nutrition and thought it would be interesting to compare it, in some detail, with diets reported from elsewhere. After a trawl through the scientific literature, I settled on three: a modern Western diet, the observed diet of modern hunter-gatherers in East Africa and an early neolithic diet.

I was shocked when I tried calculating the amounts of various chemical elements consumed. All three of these reported diets had, to within reasonable error, the same total combined intake of sodium and potassium.

The difference was that the hunter-gatherer and neolithic diets had almost an order of magnitude more potassium than sodium, whereas the Western diet was the other way around.

My idea to explain this was that we have a capacity to sense amounts of some individual dietary components, but that we lack the ability to distinguish sodium from potassium.

Perhaps this suggests that public health advice would be much more successful if it stressed increasing potassium rather than decreasing sodium.

I would love to see this exercise repeated by someone with full access to all the modern literature. Meanwhile, I suggest that the sodium appetite, one of the five suggested in the article, should really be called the potassium appetite.

Could we go diving for space rocks too?

30 May, p 41

From Marc Smith-Evans, Lantap, Philippines

I was stimulated by your article on searching for meteorites in Antarctica and a thought occurred to me. Could meteorites landing on Antarctic glaciers make their way to the ocean?

While many would travel with icebergs into the open seas, a significant proportion would be deposited near where glaciers meet the sea and fracture.

This process would have been occurring over thousands of years, so there may be relatively rich deposits in these often shallow waters. Would it be worth taking a look using remotely operated vehicles or even hardy divers?

The philosophers strike back

Letters, 30 May

From Guy Inchbald, Upton on Severn, Worcestershire, UK

Sam Edge offers us the perfect example of the problem of consciousness. He is colour-blind, but I am not, so I can never comprehend his subjective experience of seeing a rainbow, nor he mine.

All the optical and neurological science in the world can never change that. The matter is wholly inaccessible to natural science. In failing to appreciate his own predicament, it is he, not the philosophers, who is missing the point.

It is, in fact, some 2500 years since significant progress was last made in this area by philosophers. During that interregnum, they helped shape mathematics and the natural sciences. Now those disciplines are, at last, catching up and demonstrating in their own ways what Siddhartha Gautama, Lao Tzu and Parmenides understood so long ago, that consciousness is just a complex stream of delusory information, the perceived self just a construct within the stream.

To a philosopher, the natural scientist and the mathematician are something of teenagers still, scornful of their parents' wisdom yet unwilling to accept their own limitations – and a good deal less patient.

Our simulation might be an alien's search for clues

6 June, p 30

From Liz Bell, Great Shefford, Berkshire, UK

I have been following the debates in *New Scientist* about whether we are all living in a simulation. It would certainly explain some of the cosmological issues that we are still struggling with, those highlighted in the recent article by Jim Peebles, "Have we got the universe right?".

We may well be trying to analyse an imperfect universe simulation, and the more we go digging in cosmology, the more inconsistencies we will find.

A disturbing thought also occurred to me: the simulation may have been created by a different species to humans. Perhaps a species that is trying to analyse the fate of a dead planet that it discovered on its voyages.

Want to get in touch?

Send letters to letters@newscientist.com; see terms at newscientist.com/letters

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Welcome to our Signal Boost project. In these difficult times, we are offering charitable organisations the chance to take out a page in *New Scientist*, free of charge, so that they can get their message out to a global audience. Today, a message from **Wild Futures**

Emergency appeal. Can you help?

Wild Futures is the UK primate welfare and conservation charity, rescuing, campaigning, educating and providing sanctuary to primates in need.

Sixty percent of all primate species face extinction due to human activity; habitat loss, climate change, the bush meat and primate pet trades all contribute to this challenge to their survival.

Founded in 1964, The Wild Futures Monkey Sanctuary in Cornwall, UK, was the first of its kind in the world. Our innovative welfare management practices, exceptional levels of care for monkeys traumatised by the primate pet trade and our internationally recognised training and education programmes mean that our sanctuary is the only one in Europe to be accredited by the Global Federation of Animal Sanctuaries. The charity's commitment to education and skill-sharing is reflected in our board membership of the European Alliance of Rescue Centres and Sanctuaries (EARS).

Wild Futures' holistic ethos is illustrated by its commitment to maintaining wildlife habitats on the Sanctuary site whilst applying sustainable environmental policies from energy use, purchase power to recycling.

Providing support to overseas projects in habitat countries with practical assistance, skills sharing, staff secondment, funding and advice are all part of the vital work of the charity in its aim to protect primates and habitats worldwide.

Covid-19 is causing devastation all across the world and like many others we are struggling as a result of this pandemic. We are facing one of our toughest years to date.

The Sanctuary is home to 40 monkeys rescued from situations of abuse and neglect from the UK primate pet trade. As fellow primates they may be very susceptible to Covid-19; many have heart disease and diabetes as a result of their lives as pets, raising the risks further. Wild Futures is taking every precaution to protect the monkeys, splitting the team on and off site and isolating the Sanctuary. Our main priority is to make sure the monkeys have the food and the medicines they need along with continued care.

However, overnight the charity lost its main sources of income from visitors, education, volunteer and training programmes. This has huge financial ramifications. We are facing troubling times.

We are appealing for emergency help to get us through this uncertain time.

Despite the challenges, we will continue caring for the rescued monkeys in our care and continue to promote primate welfare and conservation worldwide.

Please donate today www.wildfutures.org/donate and follow us on Facebook for updates.

Wild Futures, The Monkey Sanctuary, Looe,
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Do you need your signal boosted?

If you are a charitable organisation working in science, medicine, technology, education or conservation, and would like to find out more about this project contact Chris Martin on chris.martin@newscientist.com

Our feathered friends

The Bird Way reveals how researchers are uncovering hidden aspects of the lives of birds with the help of technology, says **Simon Ings**

Book
The Bird Way
Jennifer Ackerman
Corsair

VISIT the Australian National Botanic Gardens in Canberra and you may stumble upon an odd sight: a human figure, festooned with futuristic monitoring gear. When children poke it – which happens a lot – the statue blinks.

Meet Jessica McLachlan, a researcher at Australian National University who is hard at work studying the fine, never-before-detected details of bird behaviour. The gear she wears is what it takes to observe the world as birds themselves see it.

Bird brains are miracles of miniaturisation. Their neurons are smaller and more densely packed than ours, and differ architecturally too, creating a network of close connections. As a result, bird brains operate more quickly than ours.

This means that in the bird world, things happen fast – sometimes too fast for us to see. Unless you film blue-capped cordon-bleus at 300 frames per second, for example, you will miss that they tap dance in time with their singing.

Science and nature writer Jennifer Ackerman's *The Bird Way: A new look at how birds talk, work, play, parent and think* is a fresh account of the world of birds, written to showcase the many marvels revealed by modern tracking and recording techniques. Such wonders were previously quite invisible to us. For example, by strapping tiny tracking backpacks to seabirds, we have discovered that they have a quite extraordinary sense of smell, following krill across apparently featureless horizons that are, for them, "elaborate landscapes of eddying odor plumes".

Ackerman has travelled far and talked to many, and is generous to a fault with her academic sources. Her descriptions of her visits, field trips and adventures are engaging, but never obtrusive.

The book centres primarily on the bird life of Australia. This is, after all, where songbirds evolved, as did parrots and pigeons. Like every ornithological writer before her, Ackerman is besotted by the sheer variety of her subjects.

> **"Drongos mimic up to 45 alarm calls to frighten other species into dropping their lunch"**

MAURITIUS IMAGES GMBH/ALAMY

Blue-capped cordon-bleus tap dance as part of their courtship displays

One of the most endearing passages in the book compares parrot and corvid species. Both groups are intelligent and highly social. Yet after 92 million years of evolutionary separation, the similarities stop there.

Ravens, which are corvids, are frightened of novelty. Keas, a type of parrot, lap it up. When faced with a new researcher, keas will abandon a task to go play with the stranger. Ravens will simply wig out. They also have a strict feeding hierarchy, while curious male keas will stuff food down an unfamiliar youngster's gullet until it is fending them off.

Ackerman's account is often jaw-dropping, and never more shocking than when she assembles the evidence for the cultural sophistication of birdsong. Birds decode far more from sounds than we do, and until recently, their acoustic complexity had gone unheard.

Japanese tits, for instance, use 11 different notes in their songs, and it is the combination of notes that encodes information. Swap two notes around, and you elicit different responses. If this isn't quite syntax, it is something very like it. The drongo has absolute control over its song, using up to 45 mimicked alarm calls to frighten other species, such as meerkats, into dropping their lunch – and it will target specific warning calls at individuals so they don't twig what is going on.

Meanwhile, many different species of bird worldwide, from Australia to the Himalayas, appear to have developed a universal signal to warn of the approach of brood parasites (cuckoos and the like).

If the 20th century was the golden age of laboratory study, the 21st is shaping up to become a renaissance for the sorts of field studies Charles Darwin would recognise. Now that cybernetically enhanced researchers like McLachlan can follow individuals, we have a chance to gauge and understand their intelligence. Intelligence is, after all, really hard to spot. It doesn't suit tabulation or statistical analysis. Intelligent behaviour is unusual. It is novel. It takes a long time to see.

If birds are as intelligent as so many of Ackerman's stories suggest, though, then this may only be the start of our problems. In Sweden, for example, corvid researchers Mathias and Helena Osvath have befriended a raven who turns up for their experiments, aces them, then flaps off again. "In the ethics section of grant applications," says Matthias, "it's difficult to explain." ■

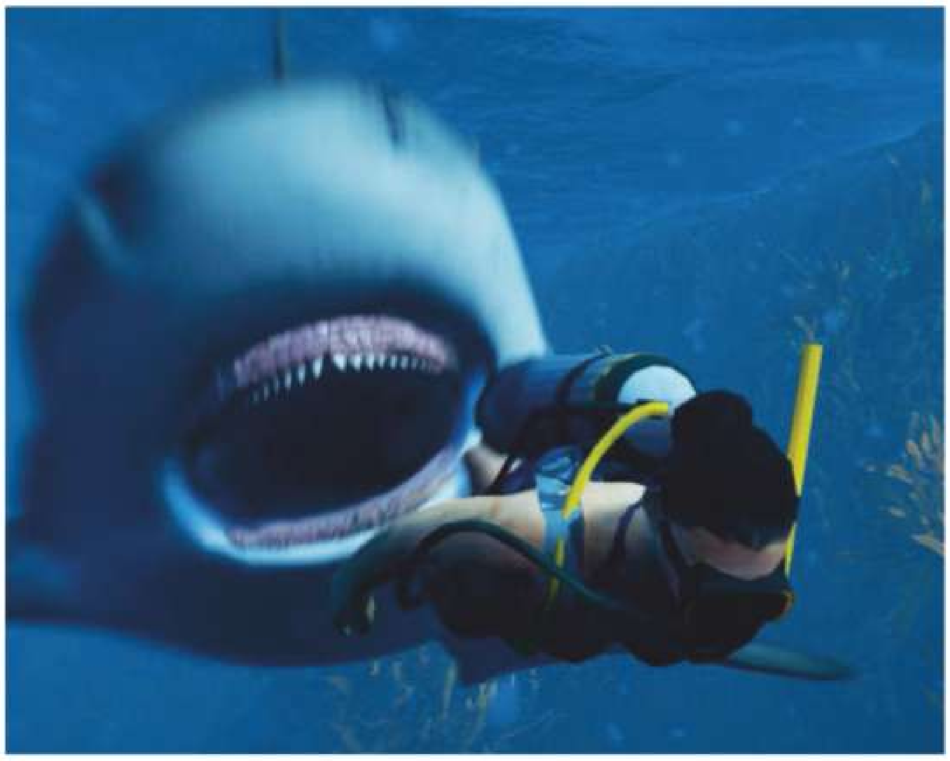
Animal antics

Playing as a murderous shark on a rampage isn't nearly as fun as being a mischievous goose terrorising a village, finds **Jacob Aron**

Games

Maneater
Tripwire Interactive
PC, PlayStation 4, Xbox One

Untitled Goose Game
House House
PC, PlayStation 4, Xbox One, Nintendo Switch


BLINDSIDE INTERACTIVE

In *Maneater*, you play as a vengeful shark on a killing spree

STEVEN SPIELBERG has a lot to answer for. The murderous shark of his classic film *Jaws* cemented the great white as a terrifying threat in the minds of millions of people, and marine biologists have been fighting back ever since. Shark attacks are actually about 10 times less deadly than fireworks, according to the International Shark Attack File (yes, such a thing exists), but I have never seen a film about a killer firework.

Even though I think sharks have been given an unfair reputation in the media, I was looking forward to getting my hands on *Maneater*, a recently released game that places you in the fins of these awesome predators, then sends you on a murderous rampage. The shark in *Jaws* kills five people over the course of the film, whereas I had eaten double that in the first 15 minutes of *Maneater*.

The game's paper-thin story sees you playing as a shark pup, whose mother was killed by a hunter named Scaly Pete. Pulled from her uterus, you eat his arm before being thrown back into the sea, where you… plot your revenge? It isn't quite clear. From there, the game tasks you with swimming around a variety of locales, eating smaller fish (and humans) to grow bigger, while avoiding larger animals like alligators until you are tough enough to take them on.

The open-world structure is loosely based on the *Grand Theft Auto* series, in which you drive around a city committing crimes, but the trouble is that there just isn't much for a shark to do. You can swim, eat and ludicrously jump onto land and flap about until your oxygen runs out, but this isn't much to build a game on. After being told to eat yet another group of fish, and wrestling with controls that made me feel more like a beached whale than a great white, I decided my time was better spent elsewhere.

> "*Maneater*'s controls made me feel more like a beached whale than a great white"

Still in the mood for animal shenanigans, I turned to *Untitled Goose Game*, which was released last year and instantly filled the internet with delightful memes. You play as a goose causing chaos in a quaint English village, and I was charmed straight away by its unsteady waddle and angry honk.

As with *Maneater*, control options are limited – you can walk, honk, flap your wings and grab objects in your beak – but developer House House cleverly makes the most of this minimalism. You are given a bare-bones list of goals, such as soaking a gardener with water or stealing a man's slippers, and left on your own to figure out how to actually achieve them.

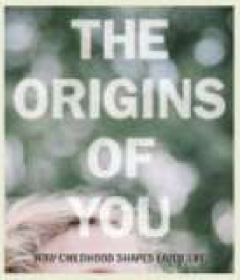
Succeeding requires a stealthy approach, distracting the villagers with a well-timed honk while you scarper off in another direction. It is impossible to fail, because if you are caught, the villagers merely chase you away and start rearranging anything you have tried to pilfer, setting you up to try again. Stealth games are a well-worn genre, but ditching spies and silenced pistols in favour of a mischievous goose is a welcome refresh.

The final level, which sees you run through the entire village while avoiding being caught, gave me a much-needed laugh at the absurdity of it all. Let's have more games starring silly animals and fewer shark massacres, please. ▮

Don't miss

Watch

Dark, a German-language Netflix thriller about disappearing children, releases its mind-bending final season on 27 June. Next to this difficult but rewarding dish, *Stranger Things* is a mere dessert.



Read

The Origins of You explains how children develop and how best to help them thrive. It is written by four researchers who were involved in a massive project that tracked the lives of thousands of people from birth to midlife.

Visit

We Are Not Alone will transport you thousands of years into the future. This star-studded online experience, put on by the Louvre Abu Dhabi, is a sonic adventure in which superintelligence and interstellar travel have become the norm.

T & B: NETFLIX; MOHAMED SONMJI/SEEING THINGS

Crystal waters

Photographer Phillip Chang
Agency Shutterstock

A FLOCK of flamingos flies across this otherworldly background in the Great Rift valley.

Phillip Chang, an amateur photographer from the US, took this shot from a helicopter about 150 metres above Lake Magadi in Kenya. The lake is alkaline because of sodium carbonate emerging from hot springs in its bed.

The coloured swirls are due to mineral disturbance. "It was the rainy season, so the water was deeper than normal," says Chang. "The colours were created by the quartz or siliceous chert and debris floating on top of the water."

Flamingos develop their signature pink plumage thanks to carotenoid pigments in the algae and invertebrates they feed on. Rosier feathers are a sign of good health and attract mates.

A recent study by Laura Soole at University Centre Sparsholt, UK, and Paul Rose at WWT Slimbridge Wetland Centre, a wildlife sanctuary in Gloucestershire, UK, found that flamingos' colour can also give an indication of their aggression (*Ethology*, doi.org/dzbj).

The pinker flamingos at the sanctuary tend to be more likely to initiate fights over food than their paler counterparts. The pair say that, in the wild, this behaviour may help flamingos compete with the hundreds of thousands and sometimes millions of other birds found on the shores of alkaline lakes in sub-Saharan Africa.

Gege Li

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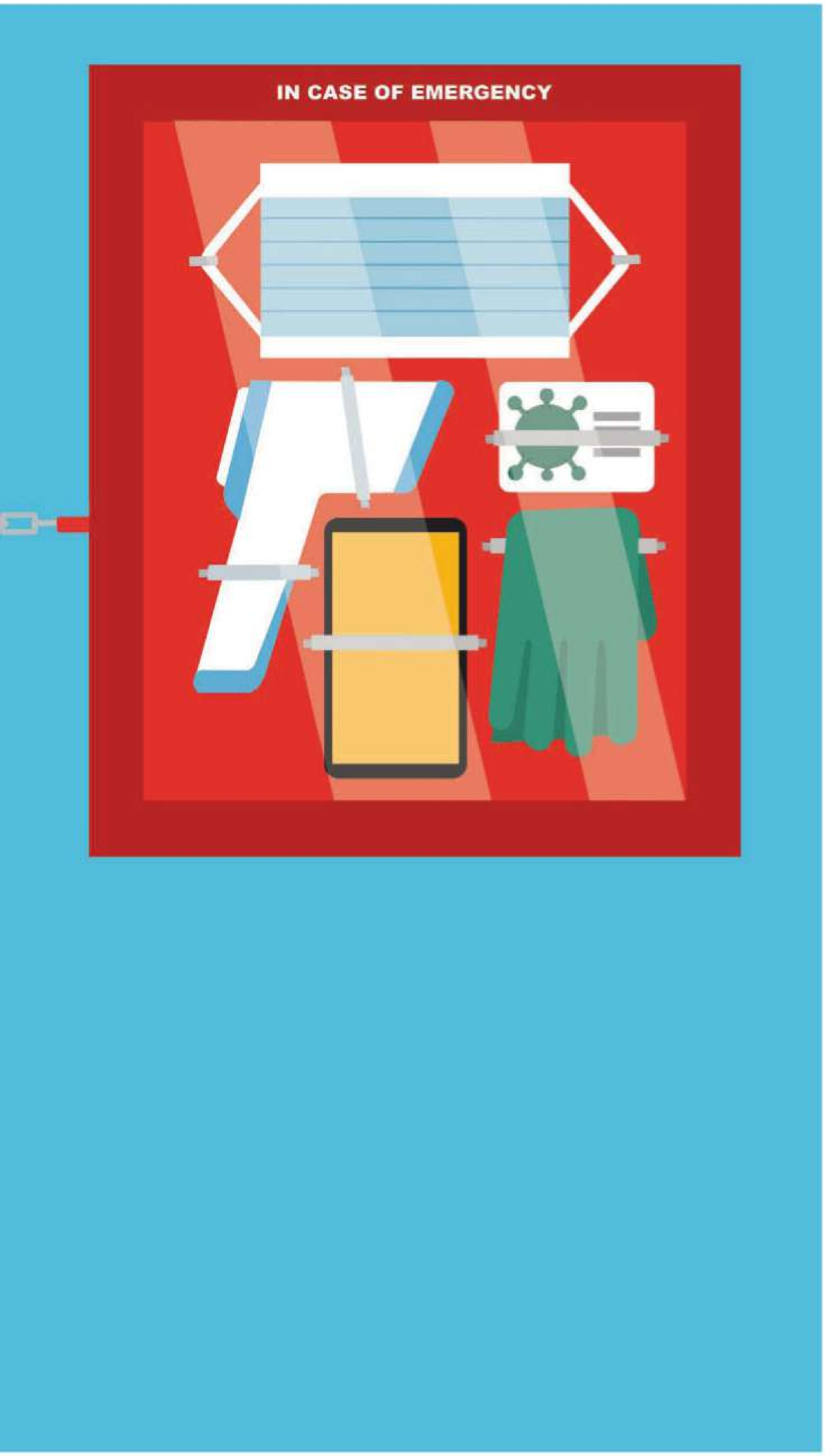
We are living through the first pandemic of a truly globalised age. It is still far from over, and its effects will be felt for decades to come. Some aspects of modern life may never be the same again. In this interconnected era, stopping the spread of covid-19 would have been an unprecedented challenge even if the global response was faultless. It wasn't – far from it.

So how can we do better? Across these 10 pages, *New Scientist* examines what it means to prepare for pandemics, what we can learn from past successes, where the next viral threat could come from and what other public health perils we need to take seriously right now.

How to stop the next outbreak



SERGIO MEMBRILLAS

Stick to the plan

Many nations failed to implement best-laid plans, others just weren't prepared. How can we make sure we're ready for next time, asks **Graham Lawton**

IF YOU are looking for certainty in these uncertain times, here is something to chew on. "There will be another pandemic," says Kathryn Jacobsen, a global health epidemiologist at George Mason University in Fairfax, Virginia. Of what, starting where and when, and how dangerous it will be, we don't know. But we had better be ready, because it could happen at any time and could be worse than this one. "We can't let our guard down," she says.

Dealing with global outbreaks is theoretically quite straightforward, says Kenneth Timmis, a microbiologist at the Technical University of Braunschweig in Germany. "Pandemics are always combated by the same basic strategy: surveillance, interruption of infection chains and the ramping up of prevention and treatment capacity." That holds true even though the nature, evolution, timing and source of new pathogens is uncertain, he says. "You don't know what you're preparing for, so you have to be generic," says Timmis. "There are certain things you have to do and these will be universal for every country and every pandemic. We therefore only need one pandemic preparedness."

And the world has one, in the shape of a global agreement called (rather prosaically for something so dramatic) the International Health Regulations (IHR).

All 194 members of the World Health Organization (WHO) have signed up to them. They are a guide to both preparedness and emergency response, and, according to Jacobsen, are largely fit for purpose.

"We need some sort of international agreement about how we're going to work together to prevent the next pandemic, but we don't need to start from the beginning, we have a good solid starting point with the IHR," says Jacobsen. To cut a very long story short, all the world has to do to be ready for next time is to implement those regulations. Unfortunately, that is easier said than done.

The IHR trace their origin to the cholera epidemics that roiled Europe in the 19th century and inspired the first global health treaty, the International Sanitary Convention of 1903. Following the founding of the WHO in 1948, it adapted this into the International Sanitary Regulations, which in 1969 were superseded by the International Health Regulations. The aim was to prevent the spread of six diseases: cholera, plague, typhus, relapsing fever, smallpox and yellow fever.

In 1995, the WHO began revising the IHR to reflect the changing global health landscape, including the eradication of smallpox, the growth of international travel and trade, and the threat of emerging diseases such as Ebola. A decade later, the member states signed off the new IHR and they entered into force in June 2007. Their overall goal is "to prevent, protect against, control and provide a public health response to the international spread of disease (in ways that are commensurate with and restricted to public health risks, and which avoid unnecessary interference with international traffic and trade)".

The regulations are available in six languages and run to some 80 pages. They address everything from monitoring infection risk at a country's points of entry to best practice for looking after people's personal health data during a crisis. They also set out how long it should take for countries to assess and respond to reports of new threats.

That includes declaring and then dealing with – apologies for the jargon overload – public health emergencies of international concern (PHEIC), including pandemics. (They even helpfully provide a flow chart for nations to determine whether their emergency meets this threshold.) Since 2007, there have been six such emergencies: the 2009 H1N1 swine flu; polio eradication setbacks in 2014; the Ebola epidemics of 2014 and 2018; Zika virus in 2016; and now covid-19.

With covid-19, the WHO declared a PHEIC on 30 January, by which time there were

> "It made a difference whether countries had pandemic experts at the heart of government"

In Sejong, South Korea, thermal scanners were in use by late February (top). Live animal markets, such as this one in Hong Kong (right), are now under scrutiny

SANDRA EMINGER/ALAMY

YONHAP NEWS AGENCY/PA IMAGES

confirmed cases in 20 countries, including China, Thailand, Japan, France, Australia, Germany, India and the US. The UK and Italy both confirmed their first cases a day later.

The announcement automatically triggered procedures laid out in the IHR: convening an emergency WHO committee and coming up with recommendations for action. One of those was that all member states should urgently review their preparedness plans and, crucially, get ready to identify, isolate and care for people with the illness, and hence shut down transmission (see "Containing a pandemic, step by step", page 36).

The WHO kept on banging the drum. A few weeks later, a report on the situation in China said that all countries – even those with zero cases – should "immediately enhance surveillance for COVID-19 as rapid detection is crucial to containing spread".

The message didn't get through to everyone. On 11 March, the WHO officially declared a pandemic. At that point, Italy, Spain, France and Germany – the hardest-hit countries in Europe at the time, with exponential growth of cases and more than 900 deaths between them – were only offering tests to people with symptoms, even though it was becoming clear that cases could be asymptomatic but still contagious. Iran, the worst-hit country in Asia after China, had no testing policy at all.

On 16 March, WHO director general Tedros Adhanom Ghebreyesus warned that the world was still not doing enough, especially in relation to testing, isolation and contact tracing, which he said were the "backbone" of the response. "We have a simple message to every country: test, test, test," he said.

Some countries followed this advice. South Korea had already set up a widespread testing regime, including thermal imaging cameras at airports. People confirmed as having covid-19 were required by law to go into isolation. Everyone they had come into contact with was intensively – and sometimes intrusively – traced and tested. These measures quickly contained the outbreak and no lockdown was necessary. In early May, the country even began easing its social distancing measures, though it reintroduced them weeks later in response to a spate of new cases. As of 8 June, South Korea had had just 11,814 confirmed cases and 273 deaths.

Other countries didn't follow the advice and failed to contain the outbreak. The UK began a testing and contact tracing programme in February but abandoned it soon after for reasons that, according to the House of Commons science and technology committee, still haven't been adequately explained. At the time of writing, the country is beginning to ease restrictions but has upwards of 290,000 confirmed cases and more than 41,000 deaths among those who tested positive for covid-19.

It may be that countries that experienced previous pandemics took this threat more seriously, sooner, and have better contained outbreaks as a result. In the past decade, Saudi Arabia, South Korea and the United Arab Emirates all had to contend with outbreaks of the MERS coronavirus, for instance, and all three nations quickly imposed stringent restrictions for covid-19.

Another factor that seems to have made a big difference in countries' responses, says Timmis, is whether they had pandemic experts at the heart of government. "Without such expertise, responses to catastrophes will generally be slow, ad hoc and inadequate," he says. The US response, for example, has been widely criticised and the country now has the most covid-19 deaths in the world. A recent editorial in the medical journal *The Lancet* argued that much of this faltering response was due to political decisions that are "marginalising and hobbling" the US Centers for Disease Control and Prevention.

Fail to prepare...

Yet many popular hypotheses about why some countries are doing well and others badly aren't supported by the evidence, says Thomas Hale at the University of Oxford, who co-runs a research project called the COVID-19 Government Response Tracker. "There's a lot of randomness," he says. "The reason for that is we saw a lot of herd behaviour, governments copying other governments under conditions of huge uncertainty."

According to Nirmal Kandel of the WHO, the UK and South Korea started out with almost identical, very high, levels of preparedness, especially in testing capacity (both scored 100 per cent on that measure in a 2018 assessment). Clearly, preparation and response aren't the same thing, a vital lesson for the next pandemic.

Other countries were simply ill-prepared. Once the pandemic was officially declared, Kandel and his colleagues assessed every WHO member state's level of readiness, based on its most recent submissions to an annual IHR reporting process. They evaluated four categories of preparedness – capacity to prevent, detect, respond and enable (which essentially means having the financial and human resources) – and also created an overall metric called Operational Readiness Capacity. Of 196 signatories to the IHR, the team found that only 104 were operationally ready for the pandemic and just 38 were at the highest level of readiness. Fourteen nations lacked any data at all, including some advanced economies such as Greece. The lowest levels of preparedness were in low-income and lower-middle-income countries. But even in the European region › (which includes some central Asian nations) only 18 of 49 were at the highest level.

Most advanced economies scored highly, yet many also had significant weaknesses. Australia and New Zealand, for example, were rated as poor on the ability to detect diseases that can be transmitted to humans from animals; the UK fell short in detecting and responding to infectious diseases at points of entry such as airports, a glaring weakness for a major international transport hub. The US had inadequate human resources to implement the IHR. Developing economies, meanwhile, often had multiple weaknesses.

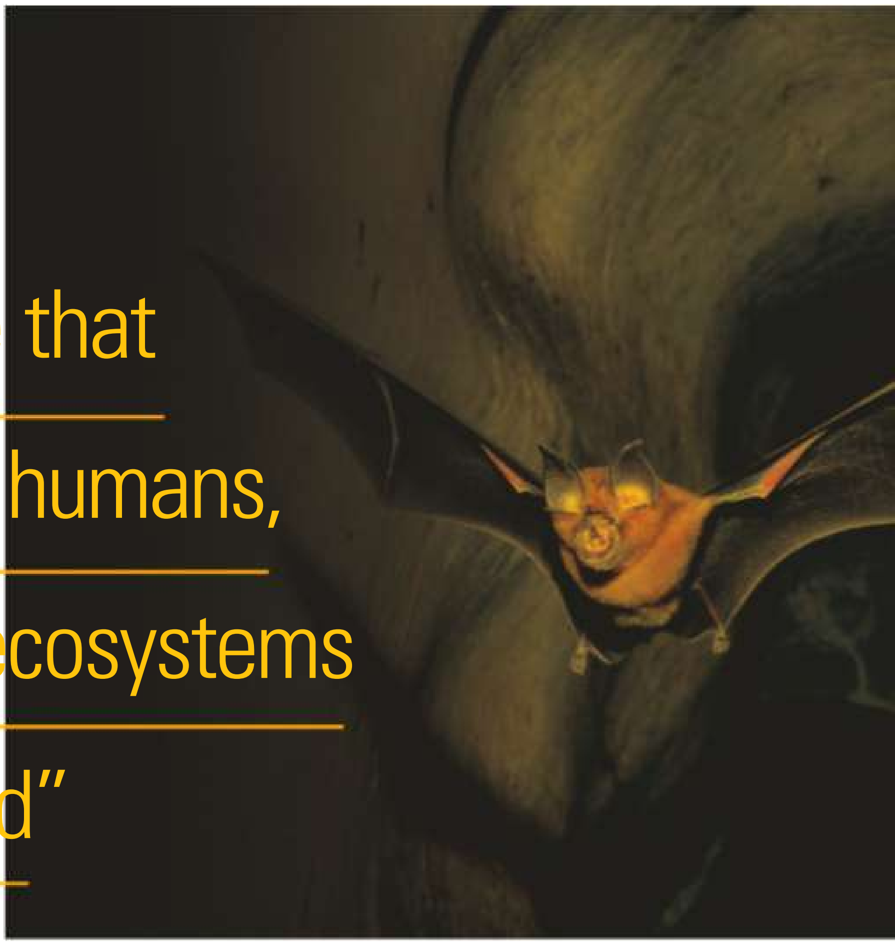
"Some countries have stronger capacities than others," says Kandel. "However, many are underprepared. All countries should invest in building greater preparedness. Investments urgently need to be scaled up."

Of course, preparedness is only half the battle. As the divergent experiences of South Korea and the UK amply demonstrate, best-laid plans can go to waste. What's more, even though advance preparation has to be generic, the response must be tailored to how infectious and deadly a pathogen is. "Different diseases will require different detailed responses," says Timmis. "But the specifics only become apparent once you're in the middle of the pandemic."

Given these significant challenges, and multiple shortcomings, what can be done? According to Kandel, in the five years leading up to the covid-19 pandemic, real progress was being made towards fully implementing the IHR. So maybe it is simply a matter of time before the job is completed, and then we must make sure the capacity stays in place.

That won't do, says Jacobsen. The IHR should still form the basis of the world's pandemic preparedness plan, she says, but they need to be fully implemented as soon as possible in every country regardless of wealth. That means high-income countries need to help low-income countries get up to speed – not as an act of charity but for reasons of self-interest. "It's really an investment in their own health security. When it comes to infectious diseases, an infection anywhere can quickly spread," she says. IHR will also need updating in the light of covid-19. "It's not a perfect document and we expect that after this pandemic, revisions will be made," says Jacobsen. "We will learn from this what we need to do for the next pandemic."

"We need to acknowledge that the health of humans, wildlife and ecosystems are connected"



As Harvey Fineberg, president of the Institute of Medicine in Washington DC, wrote in his preface to the WHO's review of the H1N1 flu outbreak in 2009: "pandemics can be fearsome teachers".

Ready for anything

Nations should also start building an extra layer of preparedness, says Jacobsen, by implementing a little-known global agreement called the Sendai Framework for Disaster Risk Reduction, which all UN member states signed up to in 2015. "Sendai is primarily about building resiliency to manage the kinds of events associated with climate change, but it also mentions pandemics," she says. "The idea is all-hazards preparedness: if countries are prepared to handle one kind of disaster they're also more prepared to handle others."

Another widely held view is that pandemic planning needs to be built on a framework called One Health, which acknowledges that the health of humans, wildlife and ecosystems are intimately interconnected. This was developed by the World Organisation for Animal Health, partly in recognition that as human populations grow, more people live in contact with domestic and wild animals and the chance of pathogens crossing between species rises.

A key part of the One Health approach is keeping an eye on potentially dangerous animal viruses. "We can assume that the most probable source of a new pandemic will be an animal virus, probably a coronavirus, whose natural host is a wild animal, possibly a bat," says Timmis. This is another area where the world needs to up its game (See "Where could the next pandemic come from?", right).

Much has been made of the need to build up capacity for more rapid development and production of vaccines and treatments in the face of an outbreak. We have made strides in this area: in 2016, the international Coalition for Epidemic Preparedness Innovations was created precisely for these reasons and it is helping to develop many of the vaccines now in the works. Improving technology is certainly a critical part of preparation, but it isn't what matters for prevention.

"We don't want to rely on new technology," says Jacobsen. "One of the challenges we have now is people saying, 'Well, we will definitely have some fill-in-the-blank technology

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CHEN JUNXIA/XINHUA NEWS AGENCY/PA IMAGES

Top: Horseshoe bats are known to carry coronaviruses; Above: WHO director general Tedros Adhanom Ghebreyesus

Where could the next pandemic come from?

Until a few months ago, many people had never heard of coronaviruses. But they aren't the only viruses that could unleash another pandemic, finds **Alice Klein**

There are estimated to be up to 800,000 viruses in animals that have the potential to infect humans. But identifying them is a task of Sisyphean proportions. One of the main programmes that seeks to detect novel viruses, PREDICT, run by the US Agency for International Development, spent 10 years and more than $200 million searching in 30 countries and managed to uncover just 931 novel viruses in wild animals, livestock and humans. Some of these are deemed potential threats to humans, including novel strains of Ebola and variants of the SARS and MERS coronaviruses. However, the project didn't detect the covid-19 virus before it spilled over into humans. Funding for PREDICT has been extended to September to support response to the current outbreak, but its primary mission ended in March.

Still, we do have some idea of what kinds of viruses to look out for. For a 2018 report published by the Johns Hopkins Center for Health Security in Maryland, Amesh Adalja interviewed more than 120 global experts in infectious disease. They agreed that a global pandemic would most likely be caused by a novel virus strain that crossed over from animals (see main story), meaning we had no immunity to it. They also thought it would spread between humans via coughing and sneezing, and that it could be transmitted by asymptomatic people or before the onset of symptoms. Sound familiar?

The experts concluded that highly deadly viruses like Ebola are unlikely to cause a pandemic because they tend to kill hosts before they can infect many others and are less likely to be spread by asymptomatic people, says Adalja. They also thought we shouldn't be too worried about something like plague, which is caused by *Yersinia pestis* bacteria, because we have broad-spectrum antibiotics that are usually effective against new bacterial strains (while we lack broad-spectrum antivirals).

They concluded, too, that DNA viruses pose less of a risk than RNA viruses, which include coronaviruses, because they are generally more stable, so less likely to mutate into deadly strains. However, the DNA virus that caused smallpox proves there are exceptions to this rule – it began its wave of destruction more than 2000 years ago after jumping from animals.

Of the 168 known virus families, the experts narrowed the field down to five that we should keep a close eye on. As well as coronaviruses, they include:

Picornaviruses

The best-known of these are rhinoviruses, which generally cause colds, and enteroviruses, which cause a range of illnesses including colds, polio and hand, foot and mouth disease.

Because they usually only cause mild symptoms, this family of viruses has largely been overlooked as a pandemic threat, says Adalja. But it is possible that they could mutate into more dangerous forms. After all, most coronaviruses only cause colds, but new deadly strains like those that cause SARS, MERS and covid-19 have spilled over from animals.

At this stage, we don't know much about the ability of picornaviruses to jump species, but there is some evidence they can cross to humans from cattle and gorillas.

Pneumoviruses

These include human metapneumovirus, which usually causes colds but can also result in bronchitis and pneumonia. Human metapneumovirus is thought to have originated in birds, and scientists believe that more deadly strains could spill over in the future.

Paramyxoviruses

Measles, mumps and croup are all caused by paramyxoviruses. The strain that causes measles is thought to have crossed into humans from cattle at least 800 years ago. There are also examples of paramyxoviruses jumping to people from bats, horses and pigs.

Orthomyxoviruses

These are "on top of everyone's pandemic list" because they include the influenza virus, which has already caused several flu pandemics, says Eddie Holmes at the University of Sydney in Australia. The flu virus is "basically everything you don't want a virus to be" as it is infectious before symptoms arise and it easily mutates and jumps between species like birds, pigs and humans.

that will end this in a couple of weeks or a couple of months'. At this point, we can't even guarantee that we'll have a vaccine, so assuming that technology will save us is not something we should rely on."

The good news is that we do have a recipe to avert disaster, built on knowledge and technologies that already exist. However, whether global preparedness will be prioritised in time for the next pandemic is a matter of political choice. President Donald Trump recently threatened to withdraw the US from the WHO and pull funding. What that would mean for the existing regulations and pandemic preparedness is unclear, but many fear it could undermine efforts to provide a coherent international response.

Regardless, it will cost money to boost preparedness, but as Timmis points out, nowhere near as much as it will cost – is costing – to deal with an actual pandemic. He argues that governments have a duty to their citizens to prepare for pandemics.

Governments may baulk at the idea of investing in resources that, by definition, are surplus to immediate requirements, says Timmis, but they spend vast sums on military capability that they hope to never have to use and should view pandemic preparedness in the same way. "It is simply one of several essential insurance premiums to which the state must commit," he says.

Right now, pandemic preparedness may seem like the most pressing and obvious priority, but, warns Jacobsen, memories are short. "I think that by the end of this calendar year, it may be hard to get countries to invest in preparedness," she says. "Panic-then-forget is how we operate. We're already seeing the beginning of the 'forget' phase as we rush to reopen economies and shift our resources to economic recovery and away from prevention, detection and treatment."

Back in 2011, the WHO concluded that the H1N1 flu pandemic could have been a lot worse. "We were lucky this time," wrote Fineberg. Maybe when we look back at covid-19 we will conclude we were lucky this time, too. But third time lucky? Don't bet on it.

Graham Lawton is a staff writer at *New Scientist*. Follow him @grahamlawton

Containing a pandemic, step by step

We've controlled international outbreaks before – and we know how to do it again, says epidemiologist **Adam Kucharski**

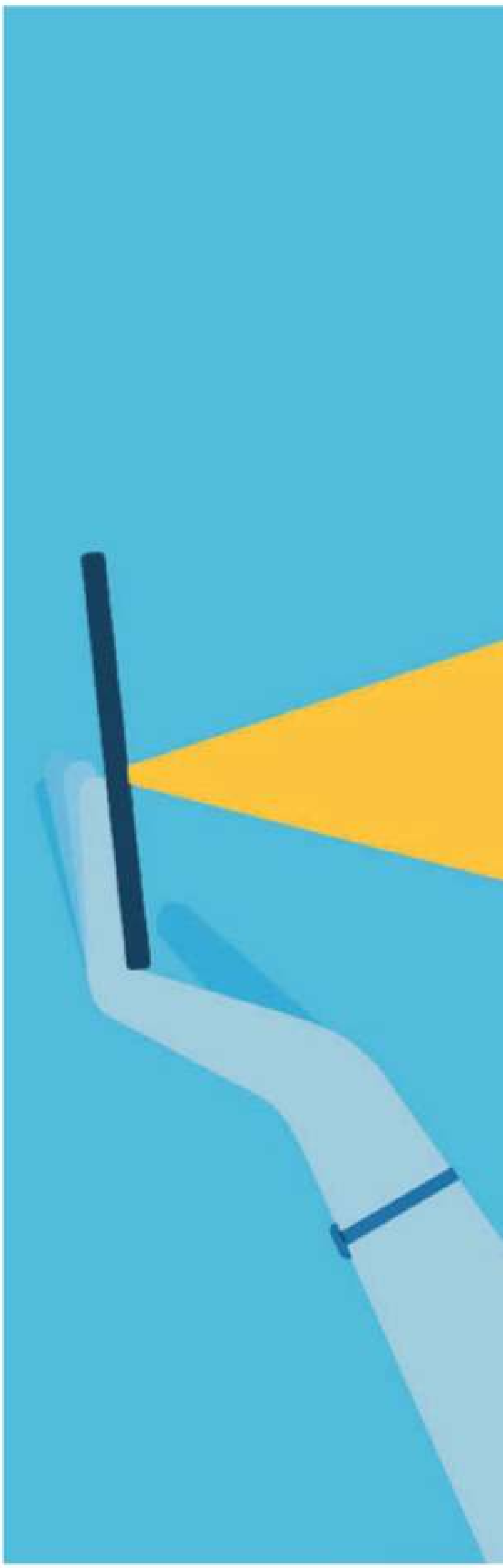
IN MAY 1997, a 3-year-old boy with a fever arrived at Queen Elizabeth Hospital in Kowloon, Hong Kong. It was a few weeks before the handover of the territory to China by the UK, and it would turn out to be a new biological era as well as a political one. The boy's disease was no usual illness: he was infected with H5N1, a strain of flu that had until then been a bird virus.

The realisation that H5N1 could infect people raised concerns that it might cause a pandemic. More than two decades later, that hasn't yet happened, with only around 800 cases having been reported globally. In the meantime, however, humanity has experienced a range of other new diseases. They include SARS, caused by a coronavirus that infected 8000 people before it was contained in 2003, and the H1N1 "swine flu", which circulated globally in 2009, probably killing more than 250,000 people. Now, covid-19 has led to more than 7 million confirmed cases, and counting.

Humanity has always experienced diseases that sweep the globe. But today, we are more exposed to them. Outbreaks spread rapidly because of widespread travel – of people, animals and animal products. And as we encroach on wilderness, viruses in animals have more opportunities to jump to humans.

When H5N1 appeared, it sparked renewed interest in the threat from pandemics. We have learned much since then. With the world in covid-19's grip, it may not feel like it, but we know a lot more than we once did about emerging diseases. That knowledge is invaluable right now. It will also help us spot – and hopefully stop – the next pandemic.

Of the thousands of known viruses, at least 200 can infect people. Some researchers have suggested that we sequence the genomes of all unidentified viruses in mammals and birds that could be a threat to us and then use



"We need to cut the transmission rate by at least 66 per cent to stop the outbreak growing"

machine-learning techniques to predict which ones could actually spread among people. But this would probably involve mapping millions of virus species, which could cost billions of dollars. Even then, it might not work. Machine learning can be very effective in situations where there is a lot of information to learn from. For example, Facebook's facial recognition is so accurate because millions of people regularly upload and tag themselves in photos. But anticipating novel disease outbreaks using machine learning would be harder – you would be trying to predict rare events with very little data because new outbreaks are far less common than social media posts.

A more targeted approach may be preferable. For a new virus to emerge and spread globally, it must overcome biological, medical and social hurdles. To cope with pandemics, we must look at each of these and identify weak points we can target to improve our chance of controlling the infection.

Emerging infections

The first step in a pandemic typically occurs before a virus gets into humans. New viral infections often start in animals. So we can try to identify viruses that are a threat to us in the kind of animals that usually harbour them before they cause us harm. We know, for instance, that emerging human diseases often originate in bats and spread to us via a range of intermediate hosts, often involving mammals and birds in overcrowded live animal markets and factory farms.

We can also target places where growing human populations have expanded into wild animal habitats. Tracking viruses in animals can certainly help us understand how and why certain infections make the leap to people. However, we still run into the problem of predicting which will cause an outbreak (see "Where could the next pandemic come from?", page 35).

Targeting the next step in the emergence of a pandemic, we can try stopping known threats from infecting us. This has worked in the past. In 2013, the H7N9 bird flu virus infected 147 people in China, of whom 47 died. In response, China closed numerous live bird markets, reducing the risk to humans by an estimated 95 per cent in

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many locations. One reason this measure was so successful is that almost all H7N9 infections were the result of bird-to-human rather than human-to-human transmission. Things could have been very different. "Detecting and tracking a partially human-adapted H7N9 virus in a city as vast as Shanghai or Beijing would be difficult; tracking a fully adapted virus would be impossible," wrote emerging disease specialist Peter Horby at the University of Oxford shortly after the outbreak.

Once a virus can spread rapidly between humans, our response becomes less about transmission from animals and more about ongoing transmission among people. In the early stages of this scenario, public health measures are usually three-pronged: isolate people who are ill, trace anyone they have had contact with and quarantine those contacts so they can't spread infection. Two factors influence the success of this approach. One is how easily the virus spreads. We measure this using the reproduction number, R, which tells us how many people an infected person spreads the virus to, on average. The second factor is how that transmission happens: is the virus spread mostly by people with obvious symptoms or can it spread when infected people still feel reasonably well? If the latter, infected people are less likely to be identified and their contacts less likely to be traced.

Take SARS. It had an R of between 2 and 3 in the early stages of the outbreak, which began in late 2002. However, because most transmission involved people who were clearly ill, contact tracing was able to bring the outbreak under control. Swine flu had a lower R of around 2 but, crucially, transmission often occurred when people weren't very ill. As a result, contact tracing was far less effective at containing the infection when it arrived in new countries. Based on current evidence, covid-19 has a similar initial R to SARS, but transmission tends to occur earlier, when people are less ill or asymptomatic. This means intensive contact tracing can slow the infection – as it has in Singapore and South Korea – but unless a very high proportion of new infections and at-risk contacts are traced, the outbreak is eventually likely to grow and additional control measures will be needed.

There is yet more we can do to reduce the spread of infection. To explain these next

Also on the watch list

Viruses are just one of a range of public health threats we need to be ready for, reports **Nic Fleming**

Vaccine hesitancy

The spread of misinformation has caused falls in measles-mumps-rubella (MMR) vaccination in countries including the US and UK, contributing to an uptick in measles cases worldwide. The collapse of HPV vaccination in Japan in 2013 due to fears about adverse events is expected to cause some 5000 extra cervical cancer deaths. Vaccine hesitancy featured on a World Health Organization list of 10 major health threats in 2019.

Yet even among people who desperately want vaccines, diminished access may be a knock-on effect of the current pandemic. In some places in Africa, people queue for 5 hours to get the yellow fever vaccine," says Sylvie Briand, director of the WHO's Pandemic and Epidemic Diseases Department. "But in other countries, where people have not experienced those kinds of diseases, we need to better communicate the benefits of vaccines."

Antibiotic resistance

A 2016 report commissioned by the UK government estimated that, globally, 700,000 people die annually due to antibiotic resistance, and that this could rise to 10 million by 2050. This includes people who catch superbugs while in hospital and lives lost to drug-resistant tuberculosis, respiratory tract infections, sexually transmitted diseases and urinary tract infections. The UN is seeking agreement for a global action plan and efforts are under way to find new antibiotics and diagnostic tools. "New antibiotics are only a short-term answer," says Tim Jinks at the Wellcome Trust, a UK-based research charity. "Long-term, we also need systems changes, such as clean water being available to patients, and healthcare workers adopting appropriate hygiene practices everywhere."

Antifungal resistance

Fungal infections are estimated to kill more people than malaria and breast cancer combined. A 2018 review described the recent rate of emergence of treatment-resistant pathogenic fungi as "unprecedented" and their effects on human health as "spiralling". Growing levels of resistance to antifungal drugs have been recorded in *Candida auris*, which has caused deadly outbreaks worldwide, and *Aspergillus fumigatus*, which triggers serious complications for people with conditions including asthma, cancer, HIV and cystic fibrosis. The Global Action Fund for Fungal Infections is calling for increased surveillance, better diagnostics and more research.

Disease X

In 2018, the WHO included "disease X" on its list of the most serious potential public health threats. It stands for any unknown epidemic disease for which preventive and curative treatments don't exist. Covid-19 fits the bill. The WHO has highlighted the value of preparing surveillance, personnel, communication and interventions for as-yet unknown risks. "For all-hazard preparedness, we need to develop generic capacity that can be applied to a variety of threats," says Briand. "Countries need actionable plans, which are exercised and questioned regularly, with a menu of interventions they can choose from depending on the type of disease."

GUIDO MIETH/GETTY IMAGES

It is hard to contain spread when a virus is contagious before symptoms appear

steps, it helps to break down R into four main components. I call these the DOTS – Duration, Opportunities, Transmission probability and Susceptibility. R depends on duration: how long a person is infectious for. It also depends on opportunities: how many interactions they have each day they are infectious. But not all opportunities will necessarily spread infection, so we also need to consider the probability of transmission during an interaction. Finally, how susceptible is the other person and could they themselves become infectious? Multiplying these four components together indicates how readily a disease can spread: R = D x O x T x S.

Connect the dots

The DOTS show how different control measures might reduce R. If we isolate people who are infected, it shortens the duration they are spreading infection. But if isolation and contact tracing alone can't contain the outbreak, we need to consider targeting other aspects of transmission. Social distancing reduces the opportunities for transmission. People who are ill with covid-19 can also reduce the likelihood of transmission by wearing a face mask. But it is important that other aspects of behaviour remain the same. If, for example, infected people lower the transmission probability by wearing a mask, but go out more and so increase the opportunities of spreading a virus, then R might remain the same – or even rise.

Because R for the covid-19 virus can be around 3 without any control measures, we need to cut transmission by at least 66 per cent to get R below 1, the level required to stop the outbreak growing. Lockdowns do this by limiting interactions. Preliminary analysis my colleagues and I did at the London School of Hygiene and Tropical Medicine found that social contacts fell by 70 per cent after the UK lockdown started. But lockdown is a blunt instrument that severely disrupts our lives.

A successful exit strategy will need to be more targeted to produce a similar reduction in transmission with less disruption. That will entail identifying situations where transmission is particularly high, which is easier in retrospect. During the SARS outbreak, transmission was high in hospitals, while funerals were "superspreading events" during the 2014 to 2016 Ebola epidemic. There have been reports of covid-19 superspreading in workplaces and at large meals and family gatherings. Curbing such risky events could disproportionately help reduce transmission, but it isn't clear how large the effect would be if other aspects of life resume.

With any infectious disease, the ultimate goal is to target the last element of the DOTS formula, by using a vaccine to reduce susceptibility. If enough people are immune, we don't have to worry so much about contact tracing or social distancing, because the virus will struggle to spread even if we behave normally. But the challenge in any pandemic is producing a vaccine that is safe, effective and widely available. Although swine flu was identified in April 2009, vaccination didn't begin until October – and this is for a strain of influenza, a well-studied disease that we routinely vaccinate against.

Vaccine timelines are improving, yet they are still much slower than the outbreaks they aim to stop. As the Ebola epidemic spread through West Africa in mid-2014, researchers hurried to generate a vaccine. Just a year later, initial results revealed one, called rVSV-ZEBOV, to be highly effective. It was a remarkable achievement – but they had an advantage. In the late 2000s, Canadian and US government scientists had shown that rVSV-ZEBOV could produce a protective immune response to Ebola in animals. So the vaccine was waiting "on the shelf", ready to be tested in people when the Ebola outbreak started.

In the past few decades, we have witnessed a surge in new viruses jumping from animals to humans. Some, like H5N1 and H7N9, caused severe disease, but stuttering transmission in humans. Other severe infections, including SARS, have been more transmissible, but we managed to contain them relatively early on through isolation and contact tracing. Our efforts to stop the spread of swine flu were less successful, but luckily it turned out to be milder than other pandemic strains. The new coronavirus combines the troublesome features of all these viruses to give a disease that is both easily transmissible and can overwhelm health systems. As for vaccines, the shelves were pretty bare.

For now, we are firefighting. We have the knowledge to bring this pandemic under control, but it has exposed countries' lack of preparedness. In the future, we need to invest in research when times are quiet. That will ensure we can respond effectively when another disease threatens, because there is no reason to assume that covid-19 will be the last – or the worst – pandemic we face. ▮

Adam Kucharski is an epidemiologist and biostatistician. His new book is *The Rules of Contagion*

ROCIO MONTOYA

Life beneath an icy moon

The frigid satellite worlds of our outer solar system may harbour extraterrestrial life. Planetary scientist **Kevin Hand** tells Daniel Cossins his plan to find it

> **"One thing we've learned is that where you find liquid water, you find life"**

OUR best shot at finding life beyond Earth may lie in the icy moons of the outer solar system – particularly Titan and Enceladus, which orbit Saturn, and Jupiter's moon Europa. We think they all have vast liquid water oceans beneath their frozen outer shells thanks to their highly elliptical orbits, which create such intense tidal forces that they are warmed from the inside out. Europa's ocean is thought to be much deeper than those on Earth, but with a similar chemical balance. Enceladus, meanwhile, spews geysers into its atmosphere that contain at least some of the ingredients life requires.

If life exists in these places, Kevin Hand wants to find it. As director of the ocean worlds lab at NASA's Jet Propulsion Laboratory in California, he is a leading expert on the potential habitability of these far-flung moons and a key player in the design of missions to explore them. In his new book *Alien Oceans: The search for life in the depths of space* (Princeton University Press), Hand describes what he has learned from his voyages to the bottom of Earth's oceans and how that informs his plans to send a life-seeking lander to Europa.

Daniel Cossins: Icy moons such as Europa are as different from Earth as one could imagine. What makes you think they might harbour life?

Kevin Hand: The simplest answer is that they are where the liquid water is. And if we've learned anything about life on Earth, it is that where you find the liquid water, you find life. In the case of Europa, its ocean is perhaps 100 kilometres deep, and we have good reason to predict that it has been around for the history of the solar system.

Combined with that, we also think that on Europa and Enceladus, a moon of Saturn, the seafloors are probably rocky and could have hydrothermal activity.

That's very important because when we think about what it takes for a world to be habitable, we know from our studies of life on Earth that it needs a couple of things as well as liquid water: the elements to build life and some source of energy to power it. On both Europa and Enceladus, we have good evidence that indicates the presence of those two things.

You are currently planning a landmark mission to Europa. What would it look for?

The first thing will be chemical signatures of life. At the most basic level, you want to look for organic compounds. Then you might also look for molecules that have chirality, meaning they are not identical to their mirror images, which is another signature of life on Earth.

You also look for inorganic indicators of life, not least cell-like structures. Life as we know it differentiates itself from its surroundings by making a compartment, the cell, and we predict that life elsewhere would form similar structures.

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New Scientist events
See Kevin Hand's exclusive virtual talk for *New Scientist* at newscientist.com/events

Do you think these places might harbour complex life?
For the most part, when I talk about the search for life elsewhere, I'm talking about the search for even the tiniest of microbes. A single-celled microbe, or the alien analogue, would revolutionise biology. But on Europa at least, I think there is a chance more complex life could have evolved.

The reason is that we've got this very intriguing relationship between Europa's surface and the magnetosphere of Jupiter, which bombards Europa with a rainstorm of charged particles. That, in turn, drives radiolysis, where water molecules are split apart and reform to make other things. We know from our observations with our telescopes and spacecraft that the surface ice on Europa contains hydrogen peroxide, sulphate and molecular oxygen. If these surface oxidants are mixed into the ocean below, you may have a very chemically rich ocean. On Earth, it was the rise of oxygen that enabled the emergence of multicellular life. So it's not completely out of the question that Europa's oceanic oxygen perhaps drove evolution to more complex life there too.

You've followed those ideas about the origin of life to the very depths of Earth's oceans, including a visit to Lost City, a system of hydrothermal vents at the bottom of the Atlantic. What was that like?
It was a transformative experience. It was like a combination of being in a time machine, transporting me back to the origin of life on Earth, and a spacecraft taking me to the deep ocean of Europa. I'm in this tiny, pressurised glass sphere, just me and the pilot, and we're looking at these cathedrals of carbonate, these chimneys that could have been the site of the origin of life on Earth. Now, there's much debate about that, and it is possible life arose in a warm pond on an ancient seashore, or in some other locale that we have yet to understand. But hydrothermal vents like those at Lost City are a strong candidate. And at that moment, I did allow myself to imagine that this could be what we would find at the bottom of Europa's ocean.

What sort of technology would we need to explore these alien oceans?
One of the wonderful things about developing a programme to search for life in these alien oceans is that we potentially get this win-win situation: we develop the tools and technologies to explore them, while simultaneously advancing our capabilities to study our own oceans. And that's where robotic vehicles like BRUIE [Buoyant Rover for Under-Ice Exploration] come into it. We've taken it down to Antarctica and demonstrated that it can help us study life at the ice-water interface here on Earth. But ultimately, we hope that BRUIE is kind of like an early ancestor – the *Australopithecus* to a robotic vehicle that eventually makes it to Europa.

What are the prospects for a mission that drills into the ice, or even gets samples from the oceans?
I would love nothing more than to do the dream of all dream missions, which is getting a submersible directly into these oceans. But scientifically and technologically, we need to follow a bit of a progression. We've got a commitment to a fly-by mission called Europa Clipper, scheduled to launch in the mid-2020s, and that mission will assess habitability. But it won't be able to search for biosignatures. I would hope that the follow-on mission would get to the surface with capabilities to directly search for signs of life, while also doing a lot of the measurements that we'd need to inform a mission that would drill or melt through the ice.

Keep in mind, though, that other than on the moon and Earth, we haven't drilled deeper than about 10 centimetres anywhere in the solar system. So going directly to a world like Europa and drilling through many kilometres of ice is an incredibly tall order, technologically speaking – and very expensive. Funding for such a mission, and

> "I'm in this tiny pressurised glass sphere, just me and the pilot, looking at these chimneys that could have been the site of the origin of life on Earth"

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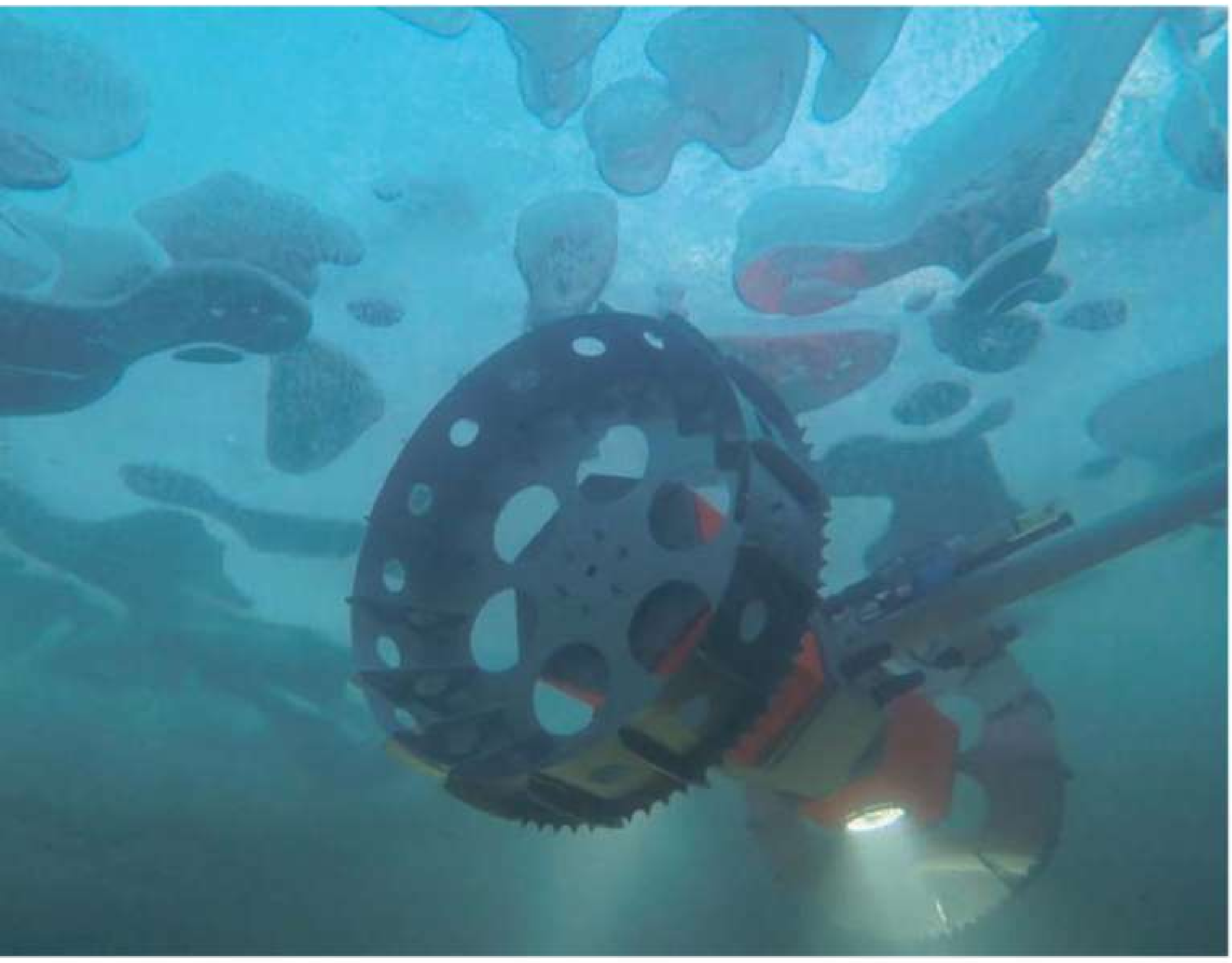


NASA/JPL-CALTECH

The BRUIE rover, tested under the Antarctic ice, could inspire probes that will one day explore alien oceans

the scientific motivation, would require initial surface reconnaissance.

If we were able to spot complex life in these oceans, what would it look like?
My experience at Lost City inspires my thinking on this. As I was collecting samples, I saw this undulating, shimmering, glass-like sheet of a creature just a couple of metres away. It looked kind of like a very large, translucent umbrella, nearly 2 metres across, and it was presumably filter-feeding on the microbes and other organisms surviving from the chemistry of the hydrothermal vents. So when I think about the prospect for larger life within an alien ocean, it is these sorts of creatures that come to mind.

Apart from your plans to send a lander to Europa, what is the most exciting thing happening in astrobiology at the moment?
In the next two decades, we will send the Dragonfly spacecraft to study Titan, another moon of Saturn, and it will be equipped to look for any biosignatures. We think Titan has a subsurface liquid water ocean sheltered beneath its icy crust, though we don't know much about the extent of the water-rock interaction there, which is important because it's really the rocks that give you those other elements that life needs.

What makes Titan a great place to search for weird life, life completely unlike any life form that we know of here on Earth, is that it has liquid methane lakes and seas on its surface. Liquid methane has very different chemical properties to liquid water, allowing all sorts of unusual compounds to dissolve and react within it. So there's a chance that Mother Nature could have a surprise in store for us with weird life, unlike anything that we have ever seen or been able to predict, crawling along the shores of Titan's liquid methane lakes and seas.

What would the discovery of life elsewhere tell us about the origins of life?
It would help answer a fundamental question, which is whether life arises wherever the conditions are right. That's something we address not by looking for life beyond Earth, but for a second origin of life. If we find it within these alien oceans in our own solar system, I think we can predict that we live in a biological universe.

Contrast that with finding life on Mars. I love Mars. But even if we're being incredibly optimistic and we say we found extant life beneath the surface of Mars, and that life is based on DNA, I would argue that you have to hedge towards conservativism and say that it would be indicative of life on Earth seeding Mars or vice versa. These alien oceans far out in the outer solar system, however, are much harder to cross-pollinate.

How confident are you that any form of life exists elsewhere?
I prefer not to approach this from the standpoint of how confident I am or what I believe. Rather, I like to frame it as a prediction, because that's ultimately what we do in science: we formulate hypotheses and we test them. And when you consider the combination of the evidence we've amassed that these alien oceans beyond Earth are habitable, combined with everything that we've learned about life on Earth, especially the presence of microbial life in an extraordinary range of extreme environments, we can now put forth a solid hypothesis: if life emerges easily wherever the conditions are right, then these alien oceans beyond Earth should be inhabited.

What difference will it make if we find life beyond Earth?
It's potentially a revolution akin to the one Galileo ignited with his first glance up at the night sky with his telescope, observing and discovering the moons of Jupiter. With those observations, he opened the door to the Copernican revolution and our place in the universe was never the same. Here, we're talking about a revolution in the science of us: biology. And I don't know what's going to unfold out of that. But I think it's incredibly exciting to think about what we might learn from, say, discovering that we live in a biological universe where life on Earth is just one point in a vast periodic table of life. ▮

Daniel Cossins is a features editor at *New Scientist*

Carbon Recycling

Making our Future Sustainable

By Louise Dynes & Jacque Minton: SBRC-Nottingham, UK

The world relies on fossil fuels not only as an energy source but also to make plastics, synthetic fibres, and an array of everyday chemicals. Fossil resources, however, are finite and their use causes environmental pollution and giga-tonne emissions of greenhouse gas (GHG). With increasing concerns over climate change there is a growing need to replace fossil fuels with alternatives which are clean, cheap, and sustainable.

Researchers at the **UKRI BBSRC/EPSRC Synthetic Biology Research Centre – Nottingham (SBRC-Nottingham)** are taking a novel approach by using bacteria to recycle carbon waste into useful products. Using cutting-edge molecular techniques and advanced synthetic biology they have engineered bacteria (e.g. *Clostridium* spp. and *Cupriavidus* spp.) to be mini factories that synthesise useful chemicals from greenhouses gases in a process called "gas fermentation".

The Carbon Recycling Network is one of six Networks in Industrial Biotechnology & Bioenergy (NIBB) funded by the UKRI BBSRC to encourage the UK growth in Industrial Biotechnology. The network goal is to create a vibrant community of researchers, which will unravel the biological, chemical, and process engineering aspects of carbon recycling through the re-use and exploitation of single carbon (C1) greenhouse gases. The focus is on the exploitation of gas fermentation, primarily using chemoautotrophs. The Network also seeks to explore the potential of anaerobic digestion (AD) as a gas fermentation feedstock generator and has funding for research projects, conferences, studentships, workshops and outreach.

To join the Network visit:
https://carbonrecycling.net/

THE CARBON RECYCLING NETWORK

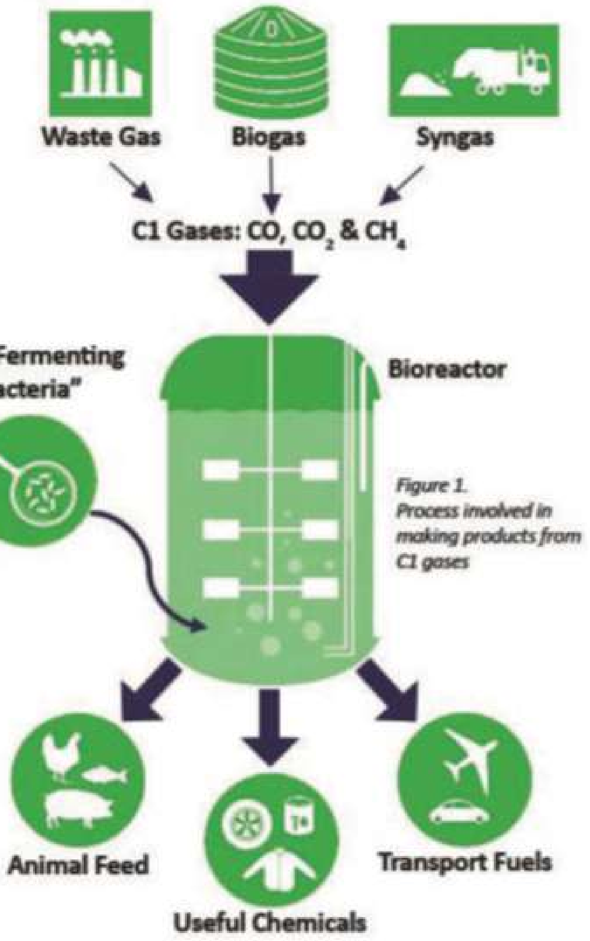


Figure 1. Process involved in making products from C1 gases

SBRC-NOTTINGHAM is a UKRI BBSRC/EPSRC funded, Synthetic Biology Research Centre led by Professor Nigel P. Minton at the University of Nottingham, UK. SBRC–Nottingham aims to provide new technologies in the form of engineered bacteria and processes that together can be used at scale by industry to transform our energy intensive economy into a sustainable and more carbon neutral bioeconomy. The Centre is collaborating with industry such as LanzaTech and Deep Branch Biotechnology to optimise and commercialise the production of low carbon fuels, everyday chemicals and animal feed using gas fermentation.

For more information visit:
https://sbrc-nottingham.ac.uk/

SynBio SBRC Nottingham
a BBSRC/EPSRC Synthetic Biology Research Centre

LANZATECH: A CARBONSMART™ SOLUTION

The LanzaTech process uses naturally occurring gas-fermenting bacteria from the acetogen family. These organisms use gases, specifically carbon monoxide, carbon dioxide and hydrogen as their only source of carbon and energy for life. LanzaTech has harnessed their natural capacity for ethanol production to enable bioethanol to be produced from carbon-rich emissions before they are released into the atmosphere. With 4 commercial facilities in development and construction, LanzaTech uses a variety of waste gases, including refinery, steel and ferroalloy emissions, as well as gases derived from unsorted, unrecyclable municipal solid waste (household waste) and agricultural residues. Since start up in 2018 in China, the first commercial LanzaTech facility has produced over 13M gallons of ethanol and reduced the equivalent of 70k tonnes of CO2 from the atmosphere, converting waste steel mill emissions to ethanol for fuel blending.

LanzaTech

These gas - fermenting bacteria are able to grow on C1 gases, such as carbon monoxide (CO), carbon dioxide (CO$_2$) and methane (CH$_4$) derived from "waste gas" from industry; "biogas" from anaerobic digestion and "syngas" from superheated domestic and agricultural wastes (see Figure 1 above).

The gas - fermenting bacteria utilise these gases as a carbon source to produce simple carbon molecules, which can be converted into an array of more complicated carbon molecules. This will enable low carbon fuels, everyday chemicals and even animal feed to be produced at scale without using fossil fuels.

DEEP BRANCH BIOTECHNOLOGY

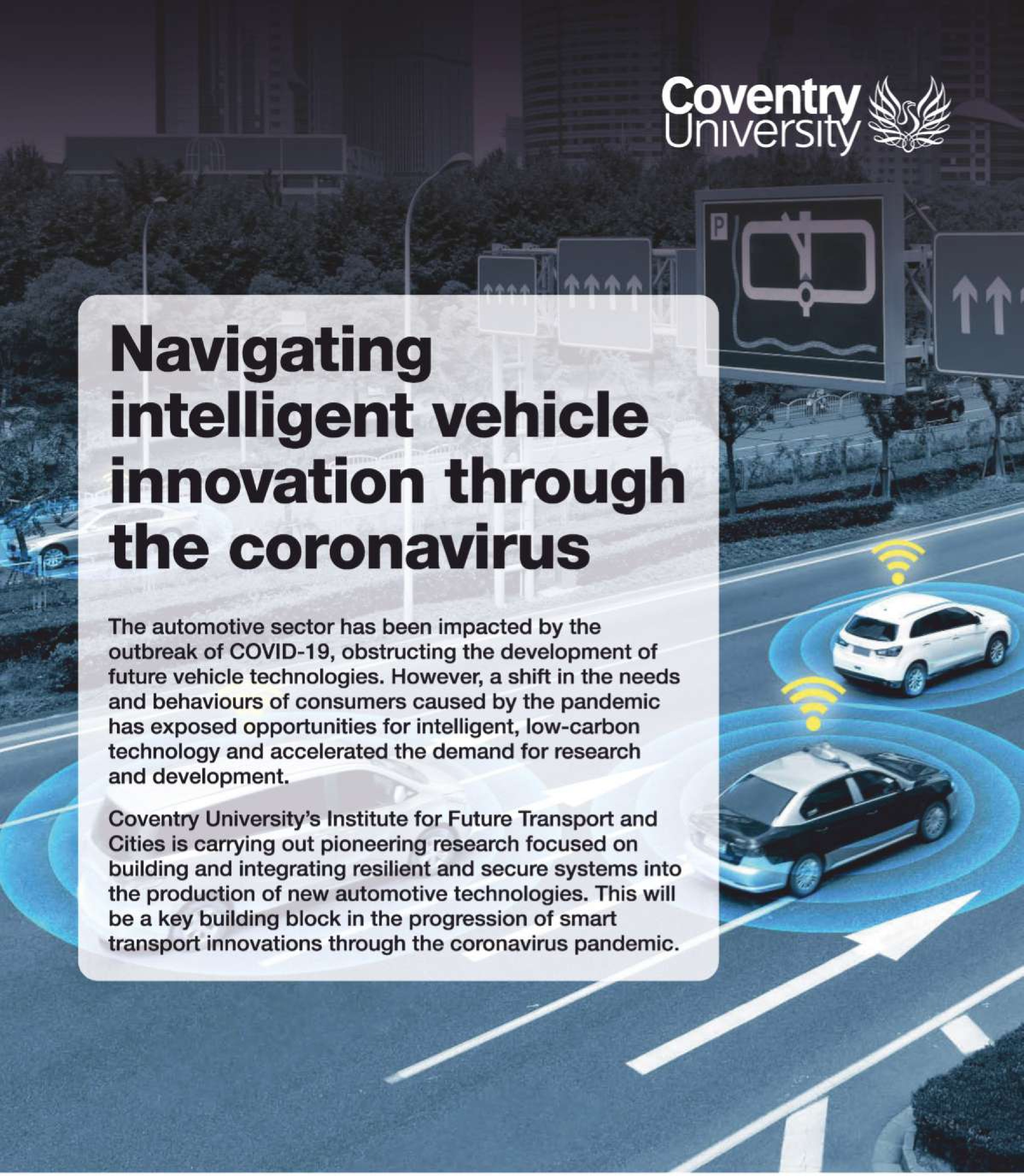
Founded in 2018, by a group of ex SBRC-Nottingham PhD students, Deep Branch is one of the newest and fastest growing companies in the gas fermentation field. Their technology is being used as a means for carbon intensive industries to improve environmental impact and their bottom line. This is best illustrated in the company's ongoing partnership with Drax, the UK's biggest producer of renewable energy. Deep Branch use carbon dioxide from the Drax's bioenergy power plant for their Mobile Pilot Unit to produce 'Proton', a nutritional tailored single cell protein for use in animal diets.

Deep Branch BIOTECHNOLOGY

University of Nottingham
UK | CHINA | MALAYSIA

UKRI Biotechnology and Biological Sciences Research Council

UKRI Engineering and Physical Sciences Research Council



Coventry University

Navigating intelligent vehicle innovation through the coronavirus

The automotive sector has been impacted by the outbreak of COVID-19, obstructing the development of future vehicle technologies. However, a shift in the needs and behaviours of consumers caused by the pandemic has exposed opportunities for intelligent, low-carbon technology and accelerated the demand for research and development.

Coventry University's Institute for Future Transport and Cities is carrying out pioneering research focused on building and integrating resilient and secure systems into the production of new automotive technologies. This will be a key building block in the progression of smart transport innovations through the coronavirus pandemic.

Research Coventry | discover more online
www.coventry.ac.uk/research

coventry.ac.uk/iftc

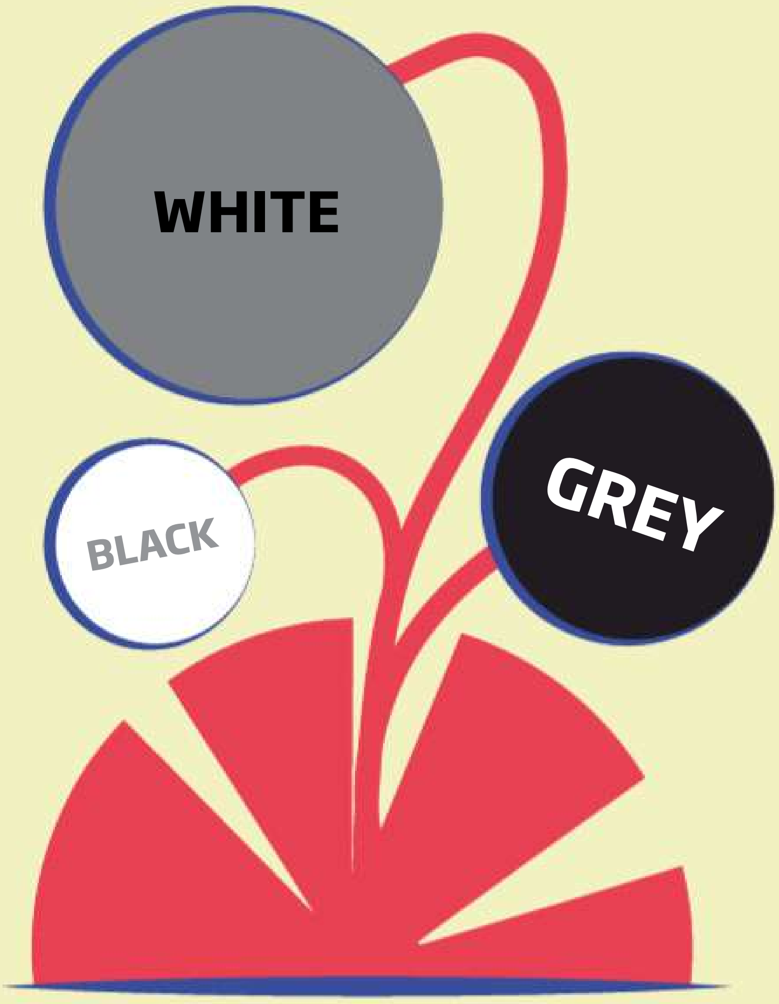
J1561-20 © Coventry University.

Test your pillars of wisdom

Human intelligence depends on a broad range of distinct skills. Put yours through their paces with these tests of different cognitive faculties, reproduced from the *New Scientist* book, *The Brain: A user's guide*. You'll find the answers overleaf, together with the answer to another burning question about intelligence: can you boost it?

1 FOCUSED ATTENTION

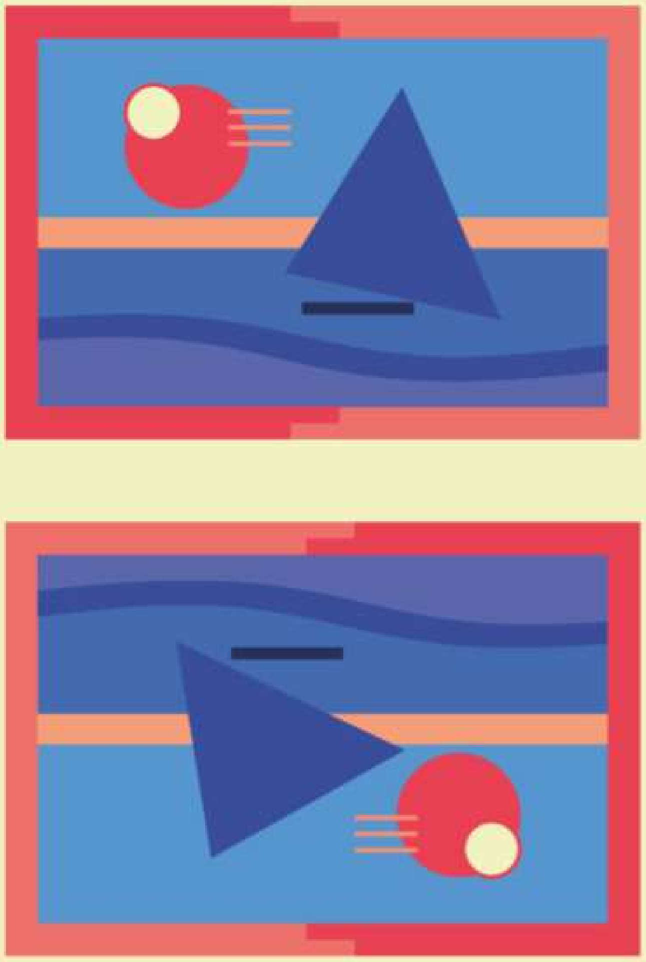
Read out the colour of the ink the words below are written in, not the words themselves.



Read a word and you will automatically hear it pop into your head. It is such a basic reaction that it is hard to inhibit. Doing so takes concentration and attention. The ability to inhibit this response can be measured by a Stroop test, like the one above, which highlights how tricky it is to identify colours and their names when the two don't match.

2 MENTAL ROTATION

If you rotated the top frame, would it be identical to the one below it? (Try to do this without physically rotating the book.)

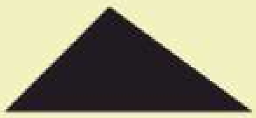


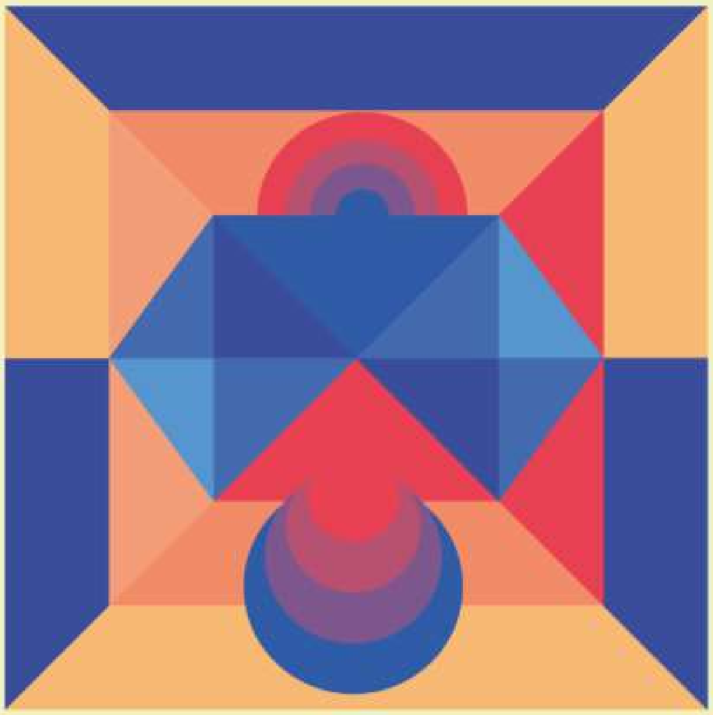
When you read a map while navigating, do you need to physically turn it to make sense of your direction or are you able to 'mentally rotate' it in your head? This skill is linked to navigation and our ability to see things from a different perspective. It underlies many everyday activities, such as finding your way home.

VALENTINA D'EFILIPPO

3 VISUOSPATIAL PROCESSING

Does this shape appear in the composition below?

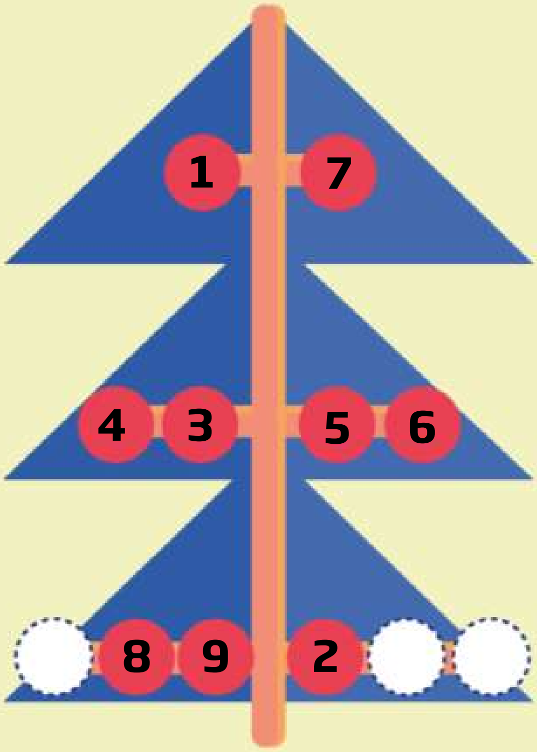




The survival of our ancestors depended on the ability to detect an important shape in a complex background, such as a lion lurking in long grass. When you mentally compare complex images with each other you rely on your brain's visuospatial processing skills. In the modern world, this is still an essential skill.

4 PLANNING

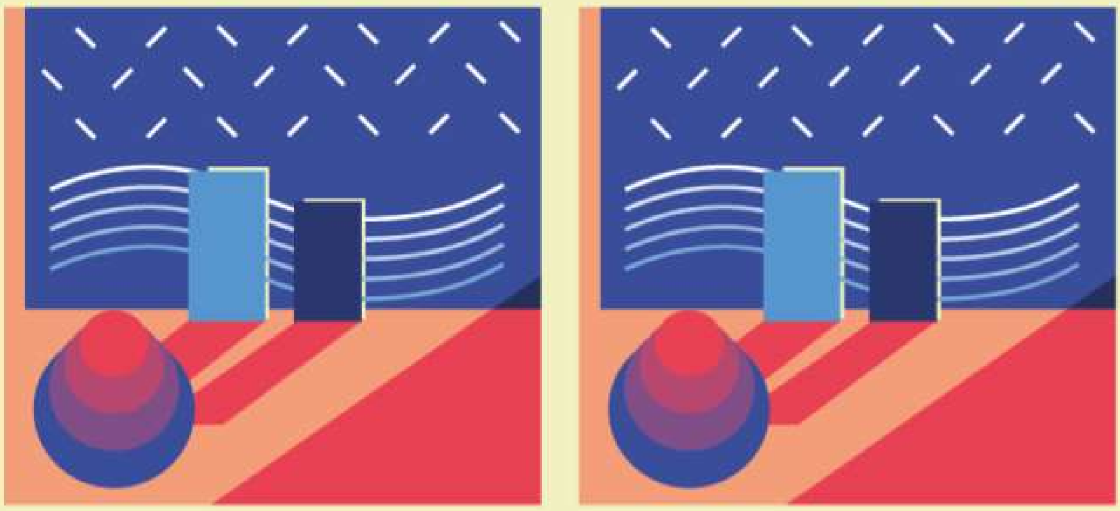
Put the numbers in order by moving a number at a time onto a vacant space. Use as few moves as possible.



Many of our daily activities are made up of a sequence of tasks that must be done in the right order. The capacity for such forward thinking can be probed with a test like the one above. The cognitive processes involved are surprisingly complex. You must create mental representations of the starting and finishing arrangements of the balls, then work out how to link them.

5 VISUAL ATTENTION

Are these two images identical?



Spot-the-difference puzzles are an old favourite in newspapers and magazines. In the most common form, two subtly different versions of an image are shown side by side, and you have to find differences between them. This is a perceptual task that tests your ability to focus your attention on complex images.

Can you boost your IQ?

We'd all like the answer to be yes. But as this extract from *The Brain: A user's guide* explains, intelligence is largely genetic – though that doesn't mean there's nothing we can do

INTELLIGENCE has always been tricky to quantify, not least because it seems to involve large tracts of the brain and so is almost certainly not one "thing". Even so, scores across different kinds of IQ tests show that people who do particularly well – or badly – on one kind of test seem to do similarly on all. This can be crunched into the single general intelligence factor, *g*, which correlates quite well with intelligence tending to lead to academic success, a higher income, and better health.

So more intelligence is clearly a good thing. Can we get more of it?

First, the bad news. Broadly speaking, your intelligence is fixed by the genes you happen to have inherited. Studies of large numbers of twins show that the IQ scores of identical twins raised apart are more similar to each other those of non-identical twins raised together. In other words, shared genes have more influence than shared environment, suggesting that nature is more important than nurture.

That doesn't mean the environment plays no part, at least in childhood. While the brain is developing, everything from diet to education and stimulation plays a huge part in developing the structures needed for intelligent thought. Children with a bad diet and poor education may never fulfil their genetic potential.

But even for well-fed and educated children, the effects of environment wear off over time. In young children, genes account for 30 per cent of the variation in intelligence scores. By young adulthood, that has risen to 60 to 80 per cent. Adult identical twins raised apart score almost exactly the same on IQ tests, while adoptees in the same household may as well be strangers. The conclusion is that most family environments are equally effective for nurturing intelligence – your adult IQ will be the same almost regardless of where you grew up, unless the environment is particularly inhumane.

Maximum cognitive ability

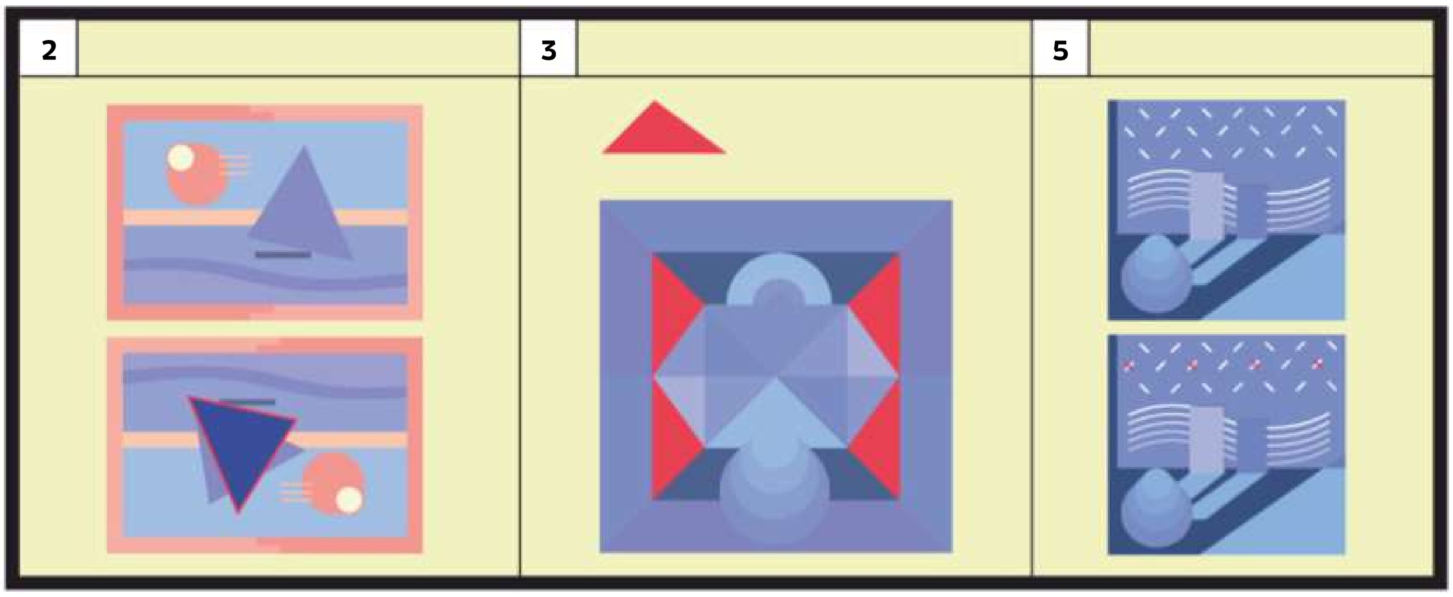
So if genes play such a big part, is there anything adults can do to improve IQ? Not much, as it turns out, though not nothing either. It is worth remembering that IQ tests are designed to measure maximum cognitive ability, but we rarely perform at that level in everyday life. Lack of sleep, stress, hunger, illness and hangovers all blunt our cognitive tools, including intelligence. So the best way to max your IQ is to avoid all of these.

Brainpower also needs protecting over the long term. Chronic illness, alcohol abuse, smoking and head injuries cause cumulative damage, but such assaults are preventable.

There are also active ways of slowing or reversing losses in cognitive function. The most effective discovered so far is physical exercise, which shields the brain by protecting cardiovascular health. Healthy body, healthy mind may be a cliché, but that is because it's true. Mental exercise, often called brain-training, is sometimes touted as a way to increase IQ, but it only boosts the particular skill that you practise. What is more, there is little evidence that the thing you get better at is transferrable outside the brain-training programme itself.

Test your pillars of wisdom answers (see previous pages):

2. See right
3. See right
4. Move 4 next to 8; move 3 next to 2; move 4 and 3 into position; move 7 into position; move 2 into position (six moves)
5. See right



VALENTINA D'EFILIPPO

Are some brains wired better?

At Einstein's autopsy in 1955, his brain was something of an anticlimax: it turned out to be a little smaller than average. Indeed, studies have suggested a minimal link between brain size and intelligence. It seems brain quality rather than quantity is key.

One important factor seems to be how well our neurons can talk to each other. The brains of more intelligent people seem to have more efficient networks between neurons – in other words, it takes fewer steps to relay a message between different regions of the brain. That could explain about a third of the variation in a population's IQ. There are indications that Einstein's brain had particularly efficient neural networks.

Another key factor is myelin, the insulating fatty sheath encasing neuron fibres. Better insulation means that nerve impulses travel faster, and there is a significant correlation between the quality of myelination and IQ.

Quick fix

Drugs offer another quick fix. Caffeine and nicotine both increase alertness for short periods, and may help you to perform close to your maximum IQ. Pharmaceuticals designed for other things are also widely used as "smart drugs".

Surveys of university students often report extensive use of the drugs Ritalin and Adderall to boost memory and concentration; both are used to treat attention-deficit hyperactivity disorder (ADHD). Another favourite is modafinil, designed to treat narcolepsy and other sleep disorders but which can also reduce fatigue and maintain alertness – useful when you need to pull an all-nighter. However, such drugs do not increase intelligence, they only enhance certain aspects of cognition such as memory or alertness. Many people are unwilling to take the risk of side effects or legal sanctions.

That might help explain the rise of so-called superfoods as natural brain boosters. Unfortunately, while eating blueberries, salmon, avocados and dark chocolate is considered safer, it may not be as effective. If such "brain foods" work at all, it is probably by promoting general health.

Some people even try transcranial direct current stimulation (tDCS), which involves placing electrodes on the scalp to pass a weak electrical current through the brain. The equipment is cheap and safe, and has been claimed to improve specific functions such as working memory, mental arithmetic, focused attention and creativity. But these are controversial claims, and if there is an effect it is only transient.

The good news is that one type of intelligence keeps on improving throughout life. Most researchers distinguish between fluid intelligence, which measures the ability to reason, learn and spot patterns, and crystallised intelligence, the sum of all our knowledge and experience gained throughout life. Fluid intelligence slows down with age, but crystallised intelligence keeps on rising. So while we all get a little slower to the party as we get older, we can rest assured that we are still getting cleverer, almost without trying. ▮

THE BRAIN: A USER'S GUIDE

Packed with fascinating science on everything from memory and sleep to the mysteries of consciousness and the self, plus surprising infographics, optical illusions, quizzes and DIY experiments, *The Brain: A User's Guide* is *New Scientist*'s ultimate companion to the most complex object in the known universe

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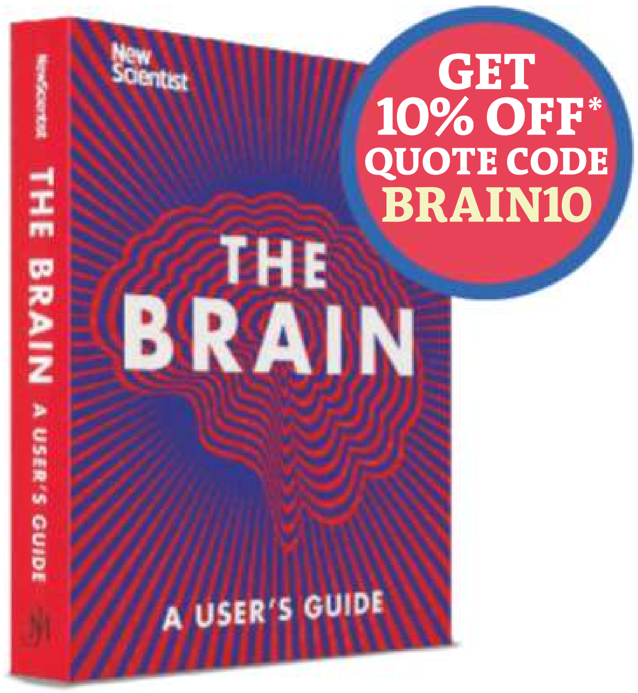

New Scientist events

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We are missing meeting our readers at our evening lectures and Instant Expert masterclasses as covid-19 had other plans. But we have still been able to bring science to life, with a series of online events. Lectures, Q&As and panel discussions streamed live and also available on-demand. Featuring *New Scientist* journalists, science experts and practitioners from around the world direct to your screen.

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HOW HUMANS ARE ALTERING LIFE ON EARTH

From selective breeding and genetic technologies to changing the biosphere, our actions are speeding up evolution, explains Helen Pilcher

9 July

WHAT HAPPENED AT THE BIG BANG?

Theoretical astrophysicist Dan Hooper reveals why recreating the conditions of the big bang is helping to the biggest mysteries of the cosmos

23 July

THE ART OF STATISTICS

Leading statistician David Spiegelhalter reveals the essential principles we need in order to derive knowledge from data

30 July

THE SCIENCE OF SIN

Neurobiologist Jack Lewis shed lights on the universally fascinating subject of temptation - where it comes from, how to resist it and why we all succumb

13 August

THE END OF THE UNIVERSE

Will our universe collapse in upon itself, rip itself apart, or even succumb to an inescapable expanding bubble of doom, asks astrophysicist Katie Mack

27 August

WHAT WERE THE NEANDERTHALS REALLY LIKE?

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CLIMATE CHANGE IN THE TIME OF PANDEMIC

Rebuilding the global economy after covid-19 and saving the planet from climate change is possible. Climatologist Mark Maslin explains how

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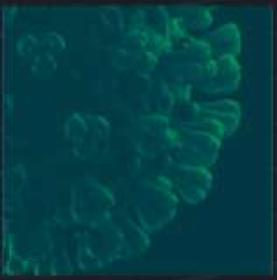
Quantum physicist Vlatko Vedral delves into the quantum nature of reality and makes a dramatic conclusion about the universe



CORONAVIRUS: CAN WE TRUST THE SCIENCE?

Our expert panel discusses why a second epidemic of preliminary, unverified and misinterpreted research has broken out – and how best to fix it

ALIEN OCEANS ON EARTH AND BEYOND

NASA astrobiologist Kevin Peter Hand explores why the small, ice-covered moons of Jupiter and Saturn offer the best chances of finding life beyond Earth

WHAT WE STILL DON'T KNOW ABOUT BLACK HOLES

Leading astronomer Chris Impey reveals what makes black holes so special and why they still haven't given up all their secrets

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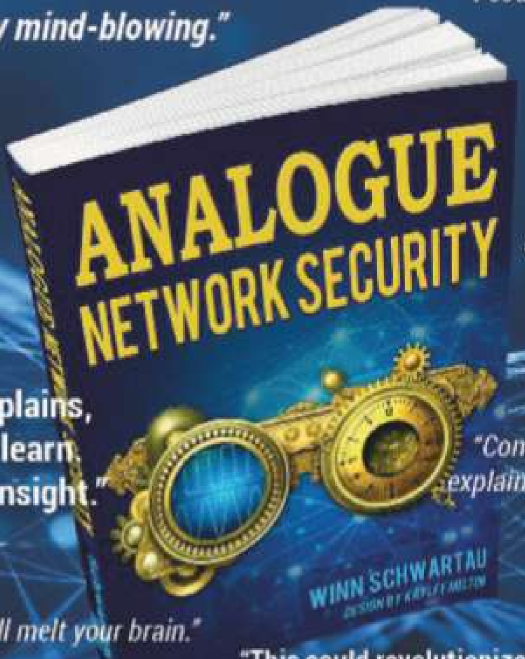

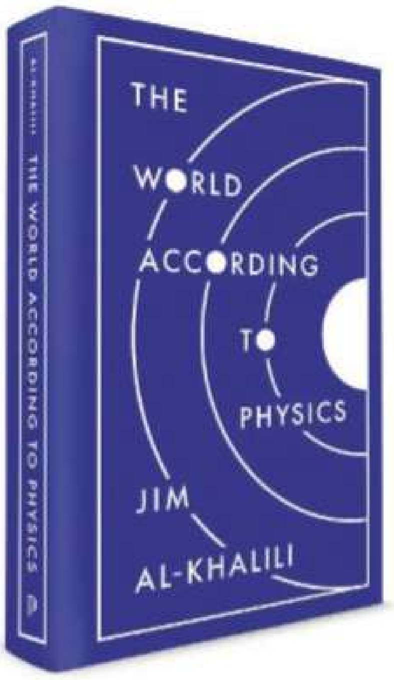

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The back pages Puzzles

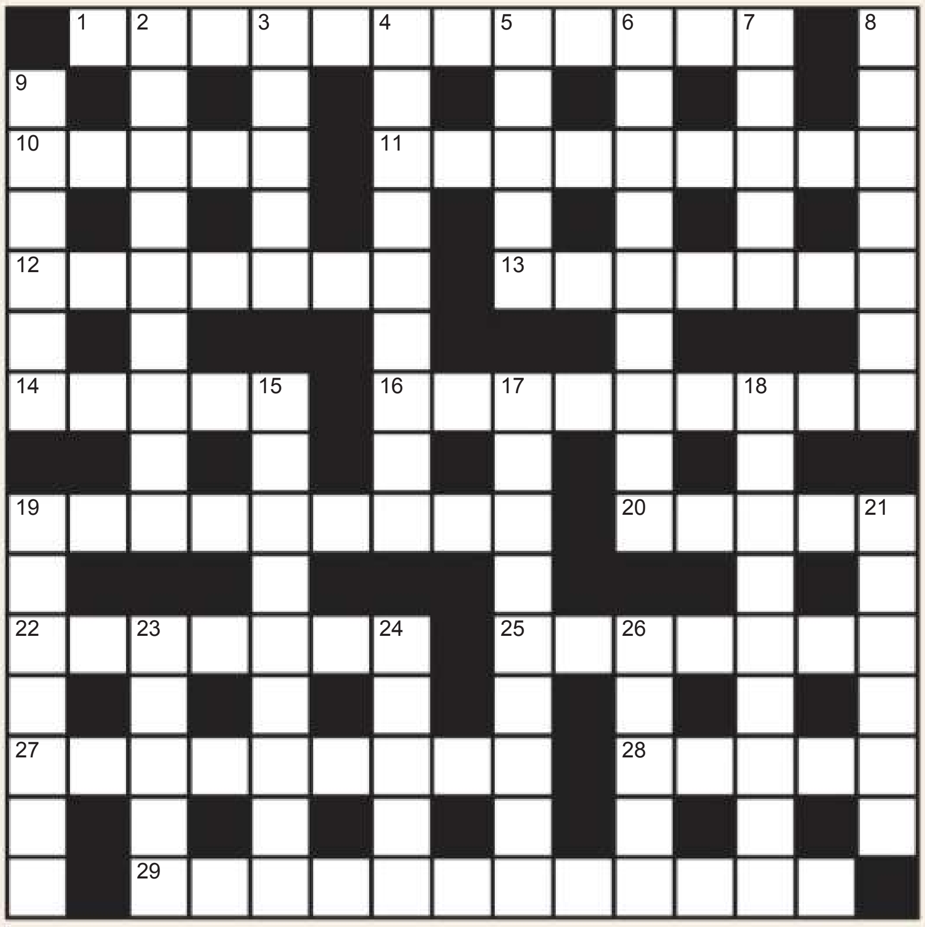
Puzzle
Calculating carpet for a doughnut-shaped room p54

Cartoons
Life through the lens of Tom Gauld and Twisteddoodles p54

Feedback
Quantum jam and pandemic pumps: the week in weird p55

The last word
The difference between magnetic and electric fields p56

Quick crossword #60 *Set by Richard Smyth*



Scribble zone

Answers and the next cryptic crossword next week

ACROSS

1 Polish author of *The Cyberiad* and *Solaris* (9,3)
10 $\aleph$ (5)
11 Painkiller (9)
12 Large clam, *Panopea generosa* (7)
13 Fundamental substance; extract, as flavouring (7)
14 Fact (5)
16 Oil, say (9)
19 Patterns; models; exemplars (9)
20 South Korean tech hub (5)
22 Part of the inner ear (7)
25 "___, we've had a problem" – Jim Lovell, 1970 (7)
27 Cyanogenic glycoside, $C_{20}H_{27}NO_{11}$ (9)
28 L-3,4-dihydroxyphenylalanine (1-4)
29 US author of *The Hainish Cycle* (6,2,4)

DOWN

2 Sci-fi character played by Jodie Whittaker (3,6)
3 ___ Zoological Park, zoo in Hyderabad (5)
4 Ignition component of an engine (5,4)
5 Rock of cryptocrystalline silica and quartz (5)
6 Organisation; system management (9)
7 Subatomic particle (5)
8 ___ grains, cereals such as spelt and bulgur (7)
9 @-ed; electronically monitored (6)
15 Flows of liquefied earth and clay (9)
17 $(CH_3)_2C(C_6H_4OH)_2$, for one (9)
18 Form of argumentation (1,8)
19 Hewing tool (7)
21 Expressible as a straight line (6)
23 Large rodent originating in South America (5)
24 $-CH_2CH{=}CH_2$ (5)
26 Herbert H. ___, US corrosion scientist (5)

Quick quiz #56

1 21:43 UTC on 20 June marks this year's June solstice, the point at which the northern and southern hemispheres are doing what, maximally?

2 What name is given to the plane in which Earth orbits around the sun, against which this is measured?

3 The name "solstice" refers to which apparent phenomenon that occurs at this time?

4 How many hours of daylight could you expect in the world's most northerly national capital around the June solstice?

5 And how many in the world's most southerly capital?

Answers on page 54

Cryptic Crossword #33

Answers

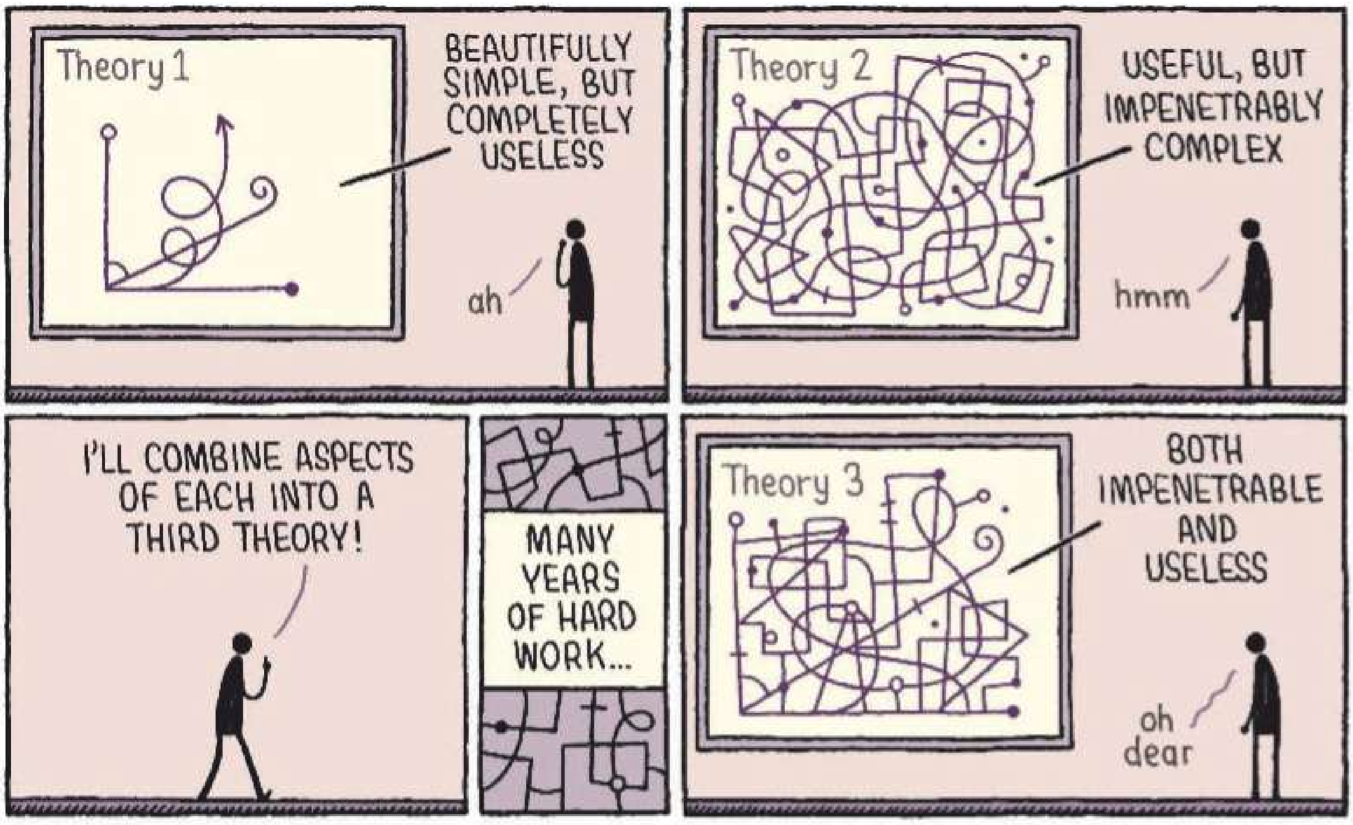
ACROSS **1** Tagalog, **5** Match, **8** Global warming, **9** Sin, **10** Scintilla, **12** Mochas, **13** Omened, **15** Gene Kelly, **16** Era, **18** Carbon neutral, **20** Lolls, **21** Desires

DOWN **1** Togas, **2** Ground control, **3** Loan shark, **4** Gawain, **5** Mar, **6** Trial-and-error, **7** Haggard, **11** Tommy guns, **12** Magical, **14** Cloned, **17** Atlas, **19** Oks

Our crosswords are now solvable online
newscientist.com/crosswords

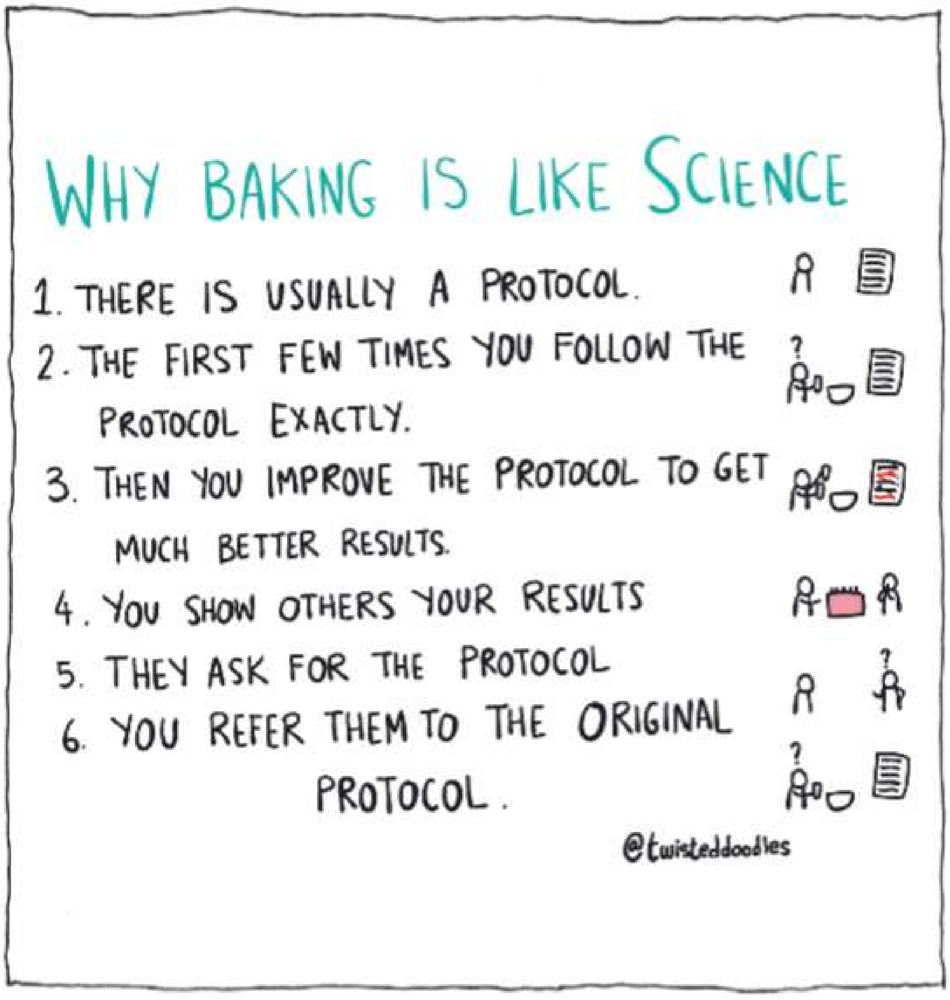
Tom Gauld

for New Scientist


Theory 1
BEAUTIFULLY SIMPLE, BUT COMPLETELY USELESS
ah
Theory 2
USEFUL, BUT IMPENETRABLY COMPLEX
hmm
I'LL COMBINE ASPECTS OF EACH INTO A THIRD THEORY!
MANY YEARS OF HARD WORK...
Theory 3
BOTH IMPENETRABLE AND USELESS
oh dear

Twisteddoodles

for New Scientist


WHY BAKING IS LIKE SCIENCE
1. THERE IS USUALLY A PROTOCOL.
2. THE FIRST FEW TIMES YOU FOLLOW THE PROTOCOL EXACTLY.
3. THEN YOU IMPROVE THE PROTOCOL TO GET MUCH BETTER RESULTS.
4. YOU SHOW OTHERS YOUR RESULTS
5. THEY ASK FOR THE PROTOCOL
6. YOU REFER THEM TO THE ORIGINAL PROTOCOL.
?
?
?
@twisteddoodles

Quick quiz #56

Answers

1 Tilting towards (northern) or away (southern) from the sun; the longest and shortest days of the year respectively occur then

2 The ecliptic plane

3 The sun "standing still" in the sky, reaching its highest (northern hemisphere) or lowest (southern) maximum point in the sky for the year before reversing

4 21 hours, 8 minutes in Reykjavik, Iceland

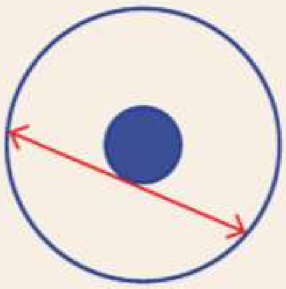
5 9 hours, 11 minute in Wellington, New Zealand

Puzzle

set by Rob Eastaway

#64 Ruritanian carpet

The newly built reception room at the Ruritanian embassy is circular. In the middle, there is a large circular pillar. All very stylish, but now it needs to be carpeted. Of course, the carpet will need to be doughnut shaped, with a hole in the middle where the pillar is. Fernando the carpet fitter needs to know the area he has to cover. This would be easy if he knew the radius or diameter of both circles, but nobody seems to know where the plans are, and when he tries to measure the diameter of the room, the pillar gets in the way. Fernando doesn't like measuring around corners, so the only thing he can think to do is to measure across the room with the tape measure touching the pillar. That distance is 10 metres. How much carpet will he need?



Answer next week

#63 What day?

It is Friday, so Carol, Dorothy and Ethel are right. Carol and Dorothy think it is Friday, Angie thinks it is Monday, Beatrice thinks it is Wednesday and Ethel thinks it is any day but Saturday or Sunday. If I told you nobody is right, it could be Saturday or Sunday. If one person is right, it could be Tuesday or Thursday. If I say two people are right, it could be Monday or Wednesday. But if I say three people are right, it can only be one day: Friday.

Quantum jam

Quantum effects are rare in the macroscopic world. Things, if you'll pardon the technical language, tend to be one thing or another, but seldom both at the same time. Otherwise you might wind up with logical inconsistencies, such as, to pick a random example, a national lockdown that people feel free to violate.

Another such mind-bender comes courtesy of retailer Marks & Spencer. "What comes first – jam or cream?" it asked in a tweet featuring a selection of summery scones. "Now you don't have to choose thanks to our new strawberry-flavoured clotted cream."

Undisturbed superposition of this kind is a beautiful thing to behold, but the true enormity of this product launch does not lie therein. At a time when people are more divided than ever, it is extremely moving to see something that anyone, regardless of age or background, can wrinkle their nose up at in disgust.

JOSIE FORD

Got a story for Feedback?
Send it to feedback@newscientist.com or
New Scientist, 25 Bedford Street, London WC2E 9ES
Consideration of items sent in the post will be delayed

Fake the jewels

It is never particularly dignified to admit to an attack of schadenfreude. This is why Feedback will, instead, insist that we take absolutely no joy from the misfortune we are about to relate.

According to an article in *The Times*, a group of armed robbers hijacked a van carrying £500,000 worth of jewellery, then seized several boxes of valuables and escaped. The criminals allegedly had inside information, which is why they struck when the van was so richly laden.

The only flaw in their cunning, devilishly well-executed plan is that their haul consisted entirely of costume jewellery, with the real swag left behind.

Two feet apart

Social distancing continues to be top of Feedback's mind, as does the proliferation of unusual techniques designed to ensure people remain the statutory distance apart.

The latest such innovation comes from the town of Cluj in Romania, where a cobbler has designed shoes so elongated that they make physical proximity practically impossible.

The prolonged pandemic pumps, so Reuters informs us, come in the equivalent of a European size 75, and need almost 1 square metre of material to produce. The effect is, perhaps, more vaudeville clown than hygiene-minded dandy, but given Feedback's own wardrobe choices, who are we to disapprove.

Far, far away

On the subject of social distancing, thank you to Barney Herring for pointing out that "safe social spacing is best maintained at a distance of 65 attoparsecs".

This distance is alternatively expressed as 20 giga-angstroms, around 13 pico-astronomical units or 10^{11} yotta-Planck lengths.

Let them equate

Time now for a story of unusually pronounced whimsy that begins with cartoonist Tom Gauld, whose regular contributions to *New Scientist* are among the highlights of any reader experience. Some weeks back, he used his cartoon to draw parallels between the detailed stratigraphic layers of, well, stratigraphic layers and those of elaborate biscuit-based desserts.

This prompted one particularly talented reader to actually make the resulting design, consisting of – and we report this with difficulty while salivating – raspberry coulis, chocolate ganache, blackberry chocolate mousse and coffee sugar syrup.

No free samples made their way to Feedback, alas, but given our chronic pandemic overeating, that is probably just as well.

As we and our colleagues united around the virtual water cooler to rhapsodise about these baked geological teaching aids, a source pointed us in the direction of yet more appetising scientific cakery.

It appears that the Nanophotonics Centre at the University of Cambridge mandates adherence to a mathematical identity that, as it appears on their website, runs as follows: "Publication=cake." Directly below this equation is a quasi-infinite scroll of scientifically accurate confectionery, ranging from optically nano-welding brownies to photocatalytic shortbread.

Let us know if you are aware of any other inhabitants of this viennoiserie Venn diagram.

Slice up the pi

In a recent column (30 May), Feedback cast an approving eye over a deliberately inefficient scheme to calculate the value of pi. This inspired George Masin to write in with the following observation: "If asked to give the value of pi in a space allowing only 7 characters, you would probably give 3.14159, but a slightly more accurate value can be given by specifying the division 355/113."

Throwing down the gauntlet to fellow pificionados, he goes on to ask: "Are there cases where a division using more characters gives pi to a greater accuracy than the number of characters used to represent the division?" Please send your suggestions to the usual address.

What's in a name?

Oh go on, have another helping of nominative determinism why don't you, we all know it's why you are here. Gather round and say hello to New York ICU doctor Rob Gore and ecological consultant Laurie Wildwood. ▮

Written by Gilead Amit

Fields apart

What, apart from their origin, is the difference between a magnetic field and an electric one?

Adam Gray
Manchester, UK
Electric and magnetic fields are both components of an electromagnetic field.

These two components occupy different planes relative to the cause of the electromagnetic field, for example a moving electrical charge. This, and whether the charge generating the field is stationary or in motion, are the only differences.

Brian Pollard
Launceston, Cornwall, UK
There is a relationship between electric and magnetic fields, in that a change in one produces a change in the other. An electromagnetic wave consists of both type of field, which are oscillating back and forth.

The relationship between electric and magnetic fields is what allows the formation of electromagnetic waves, including light and heat. This relationship is fundamental to the working of the universe in its present form.

Aside from these aspects of electromagnetism, an electric field is formed between positive and negative voltage potentials. An example of a magnetic field that most people are familiar with is produced externally between the north and south magnetic poles of a bar magnet, and continues inside the magnet between the poles, forming a loop.

All magnetic fields form these loops, a property that was discovered by 19th-century English scientist Michael Faraday. He put the loops to use in what are now everyday objects, such as electric transformers and motors.

Jason Dicker
Launceston, Tasmania, Australia
Both electric and magnetic fields are the consequence of the attraction and repulsion of electric charges. However, a magnetic effect is caused by moving electric charges while an electric field is caused by stationary charges.

For example, the magnetic field seen in a simple steel bar magnet is the result of the orbiting and spinning charges of subatomic particle.

However, motion is relative, so a person moving with a line of charges, for example, wouldn't perceive the magnetic field that a stationary person next to the moving charges would.

This effect is fully explained by Einstein's theory of special relativity, which came in 1905, nearly half a century after the Scottish physicist James Clerk Maxwell combined electricity and magnetism into a unified theory of electromagnetism in the 1860s.

While many people say that Einstein's relativistic effects can only be seen at high velocities, such as the motion of objects in space, the electrons in a wire that move as a current to create a magnetic force travel at about a millimetre per second, even if the electromagnetic wave in electric current moves much, much faster.

LEMANNA/GETTY IMAGES/ISTOCK

What stops trees from just growing wider and wider?

This week's new questions

Spreading roots **If the height of a tree is limited by capillary action, why can't trees grow to an unlimited width?** ***Jed Stephens****, Keighley, West Yorkshire, UK*

Innate taste **Are certain genes associated with a dislike of certain tastes, like coriander?** ***Philip Blackburn****, London, UK*

Cloud cover

At any one time, how much of Earth is covered by cloud? Does this vary?

Vittoria Dessi
Zuoz, Switzerland
Cloud cover locally can easily be measured by observation from a single location on the ground. It is quantified in oktas, or the number of eighths of the sky covered by visible cloud of any type.

However, on a larger scale, the distribution of cloud across Earth can be measured better from space, by beaming pulses of either infrared or visible light waves down and analysing the reflection of pulses coming from the upper surface of a cloud layer.

Earth's cloud coverage has been measured by several NASA satellites, including the Ice, Cloud, and land Elevation Satellite (ICEsat), which has provided the most accurate figure to date. ICEsat's measurements show that, on average, 70 per cent of the world is covered by cloud at any time.

This figure can vary by up to 30 per cent from day to day depending on weather conditions. For example, at higher temperatures there would be more evaporation and an increase in the moisture in the air that can condense into clouds. Annually, cloud cover varies by only a few per cent on average across the year, since the hydrological cycle is a closed system.

Brian Brown
Dronfield, Derbyshire, UK
NASA's International Satellite Cloud Climatology Project (ISCCP) has been gathering information on global cloud coverage at 3-hourly intervals for 38 years.

As part of the project, NASA has collected data from several geostationary and polar orbiting satellites. This shows the average percentage global cloud cover at any time is about 65 per cent.

The average amount of cloud cover is slightly different in the northern and southern hemispheres, possibly because there is more land in the northern hemisphere. There are also seasonal changes in cloud cover and some more long-term changes. For example, over 23 years from 1983, the average percentage cover of low cloud fell from about 12 to 10 per cent. The reason for this isn't clear.

The ISCCP data on total cloud cover includes clouds at all levels. But the percentage coverage of low cloud is much less, at about 11 per cent. Low cloud coverage is also much more variable than total cloud cover. ▮

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Clare Wilson